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by

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FOREWORD

Effective regulatory and enforcement actions by the Environmental Protection Agency would be virtually impossible without sound scientific data on pollutants and their impact on environmental stability and human health. Responsibility for building this data base has been assigned to EPA's Office of Research and Development and its 15 major field installations, one of which is the Corvallis Environmental Research Laboratory (CERL).

The primary mission of the Corvallis Laboratory is research on the effects of environmental pollutants on terrestrial, freshwater, and marine ecosystems; the behavior, effects and control of pollutants in lake and stream systems; and the development of predictive models on the movement of pollutants in the biosphere.

This report evaluates the impact of forest fertilization with urea on major chemical and biological components of stream ecosystems.

Thomas A. Murphy
Director, CERL

ABSTRACT

During April, 1976, 1.9×10^3 ha of second growth Douglas fir, located in the Willamette National Forest of Oregon, were fertilized with 224 kg urea-N/ha. Unfertilized buffer strips of 60 and 90 m were maintained along all second and third order streams, respectively. Sharp increases in urea concentrations (maximum of 12 mg/l) during the fertilization phase were due to the unintentional, direct application to the streams. Immediately following fertilization all nitrogen species returned to near background levels. The Second year following fertilization only NO_3-NO_2 appeared to be slightly elevated due to fertilization. Two-month fish bioassays using Salmo gairdneri showed no mortalities which could be attributed to by-products or contaminants of urea. Algal assays using Selenastrum capricornutum, and chlorophyll a and ATP-biomass of periphyton from glass slide samplers showed low supporting capacity and generally no significant increase in biomass resulting from fertilization. Decomposition experiments using dialysis chambers suggested little difference between a fertilized and unfertilized station. Analysis of benthic and drifting invertebrates suggested that little change in community structure could be related to fertilization. A record drought the first year following fertilization may have resulted in reduced nitrogen loss to the stream system. This report covers a period from April, 1976 to July, 1977 and was completed as of June, 1979.

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SECTION 1

INTRODUCTION

A worldwide reduction in the land base available for silviculture coupled with increasing timber demand have stimulated the development of improved management methods to increase timber growth rate (Baule, 1975; Schultz, 1975; Haines, 1975; Hansen, 1975). Forest fertilization is one technique for increasing timber yield which is gaining increased acceptance.

Groman (1972) and Baule (1975) have reviewed the global extent of forest fertilization and predict a rapid expansion of its use. Baule's review predicts that by 1980, 0.20-0.25% of the world's forest will have been fertilized at least once. While this is a relatively modest fraction, on a world scale it will involve the use of a prodigious quantity of fertilizer. And it will be concentrated in a few, highly developed nations.

A rapid increase in forest fertilization in the United States is expected. Fertilizers applied include N, P, and K alone or in various combinations. In the Southeast United States, about 100,000 ha of forest had been fertilized by 1973; this is expected to increase greatly (Haines, 1975). Schultz (1974) has estimated that in United States about 2 million ha/yr could be fertilized. In the Pacific Northwest, about 250,000 ha of forest had been fertilized with urea by 1974, with the annual rate approaching 120,000 ha/yr (Moore, 1975a). The combined fertilization potential in Oregon and Washington alone is estimated to be about one million ha/yr by 1985 (Hansen, 1974).

Growth of major coniferous timber species in the Pacific Northwest is generally limited by nitrogen (Gessel, 1969). Growth rate increases of up to 30% have been sustained for 5-7 year periods by single applications of nitrogen fertilizer (Anderson, 1969). In a review of nitrogen dynamics in forest soils, Wollum and Davey (1975) predicted that modern management techniques will place much higher demands on soil nitrogen supplies because faster growth rates mean shorter rotation times and higher nitrogen removal rates. A doubling of nitrogen demands is conceivable for conifers which store a high proportion of their mature nitrogen content early in life. Logging practices such as whole-tree utilization and in-woods chipping will also result in increased nitrogen removal.

Because of the rapid spread of this silvicultural practice, there is growing concern over possible adverse side effects (Atkinson and Morison, 1975; Safford, 1973). Laboratory and field studies on disposition of applied urea nitrogen within forest soils have revealed little likelihood of significant nitrogen transport into groundwater (Cole and Gessel, 1963; 1975; Cole et al. 1975; Knowles, 1975). These studies have shown that the ammonium ion, the hydrolysis product of urea, is quickly immobilized by soil cation exchange sites and biota. Significant losses of fertilizer nitrogen have resulted from

ammonia volatilization (Watkins et al. 1972; Chin and Kroontje, 1963; Bernier et al. 1969; Mahendrappa, 1975) and leaching to surface waters. High volatilization losses have been noted under conditions of high pH which is due to the greater proportion of non-ionized ammonia. Volatilization losses as high as 46% have been observed from forest soils in laboratory studies (Watkins et al. 1972).

Leaching of fertilizer nitrogen within forest soils has been observed mainly after oxidation of ammonium to nitrate. Heilman (1974) found that the nitrification rate in Pacific Northwestern forest soils was variable, but generally low before and immediately after fertilization. However, nitrification was much more rapid in both untreated and re-fertilized soils taken from sites which had been fertilized some years previously. It appears that initial fertilization has a "priming" effect on nitrifying organisms, which may lead to much higher rates of nitrate leaching with time and with repeated urea treatments.

Urea fertilization also increases nitrogen leaching through mobilization of organic N. Salonius (1972) noted that application of urea increased the rate of decomposition of forest humus, and Ogner (1972a,b) found greatly increased leaching of organic N to the 40 cm depth after surface application of urea.

Cole and Gessel (1974) noted that three-fourths of the usable water supply in the United States originates in the forested one-third of the country. As a result, forest fertilization practices have an inherent potential to affect a large proportion of the nation's water supply. For this reason, there have been many recent studies on streamwater contamination in fertilized watersheds.

Nitrogen losses to surface waters represent a very small fraction when expressed as percent of nitrogen applied; however, relatively high concentrations have been found. Early losses usually range from 2 to 3% of applied nitrogen for streams not buffered by unfertilized zones (Moore, 1975b) and about 0.5% for streams with buffer zones. Such losses may be significant (Werner, 1973) since they impact headwater streams which average 1 km^2 watershed per 1.4 km of stream (Leopold et al. 1964). In watersheds fertilized at the standard rate of 224 kg N/ha, a leaching loss of only 1% per year translates to a stream loading rate of 161 kg/km/yr. Consequences of the impact of this enrichment upon the biota of streams and lakes have not been determined. The only previous work of which we are aware involved two streams draining fertilized clearcuts in Alaska (Meehan et al. 1975), which showed that changes in periphyton or benthic biomass due to fertilization could not be distinguished from natural variation. Clearly, more work is needed to ascertain biological effects of forest fertilization on the large variety of stream systems which may be affected.

The present study was undertaken in response to this need. The objective of this study was to determine the impact of aerial forest fertilization with urea on major components of the aquatic ecosystem. These components included streamwater chemical composition, fish (bioassay), algal growth potential (algal assay), in situ periphyton growth, heterotrophic decomposition, benthic community structure, and invertebrate drift composition.

SECTION 2

CONCLUSIONS

The chemical parameters, other than the forms of nitrogen, demonstrated no change which could be attributed to fertilization. The nitrogen species measured in this study included urea, NH_3, NO_3-NO_2, and total Kjeldahl nitrogen. Urea increased sharply during the fertilization period when unfertilized buffer strips along the streams were violated. Due to the possible addition of NH_3 by red alder symbionts, very little could be concluded about fertilization-ammonia relationships. Nitrate-nitrite-N, however, did not appear affected by this source and increased slightly during and following fertilization. The year following fertilization, the only nitrogen species which appeared to be elevated due to fertilization was NO_3-NO_2.

The results of this study suggest that fertilization slightly increased stream nitrogen concentrations. Streams with higher flows and those that had 45 m buffer strips had lower nitrogen concentrations than streams with lower flows and 30 m strips. Also, the lack of buffer strips on the smaller headwater tributaries resulted in elevated nitrogen concentrations even though the remainder of the stream was buffered. Nitrogen concentrations in an unbuffered stream, fertilized at an application rate of about one-third to two-thirds that used for the other watersheds, were the highest of all streams studied.

Nitrogen loadings calculated for the experimental streams were low and possibly negative on occasion. Higher NO_3-NO_2 loadings the second year appear to be the residual effects of fertilization. Although nitrogen concentrations were less in comparable streams buffered by 45 m strips (Station 11) than those buffered by 30 m strips (Stations 23 and 24), loading differences were too small to be measured.

Two-month fish bioassays showed no increased fish mortality which could be attributed to by-products or contaminants of the urea fertilizer.

Algal assays conducted on water from the fertilized and control streams suggested low growth potential changed only slightly, if at all, after fertilization. Fertilization did not shift the limiting nutrient status of the water to phosphorus. The experiments did indicate that nitrogen and phosphorus co-limited algal growth.

The periphyton studies also revealed low growth potential. However, a slight but significant (0.05) difference in chlorophyll a was noted between control and selected experimental slides exposed for 8 weeks. Slides exposed for 4 weeks showed no significant difference, and biomass in the control and experimental stations was not significantly different for either 4 or 8 week

exposures. This indicates that fertilization may have increased autotrophic growth, although the combined autotrophic-heterotrophic supporting capacity did not change.

The heterotrophic decomposition of Douglas fir needles and red alder leaves also suggested a low supporting capacity for the heterotrophic component of the stream biocoenosis. Fertilization caused no measurable difference in decomposition between the control and experimental streams.

Benthos and invertebrate drift components of the aquatic ecosystem also showed no change which could be attributed to fertilization with urea. The changes which did occur in benthic community structure and invertebrate drift composition appeared more dependent upon emergence, flow, and season than any other factors.

Violation of buffer zones resulted in temporary high nitrogen concentrations, and the lack of any buffer zone along streams resulted in the highest nitrogen concentrations. Also, fertilization of unbuffered headwater tributaries appeared to partially nullify benefits gained by buffering the main stream channel. Although nitrogen species were sometimes slightly elevated following fertilization, other chemical and biological parameters, except for periphyton, showed no change which could be attributed to fertilization.

Although fertilization appeared to cause a slight enhancement of autotrophic growth, the autotrophic-heterotrophic biomass supported by the streams was not altered. Possible changes in supporting capacity which might have occurred in response to the slightly increased nitrogen concentrations were probably mediated by co-limitation of phosphorus. Had phosphorus not been co-limiting, or had this additional nitrogen been transported to a nitrogen-limited stream, increased growth may have resulted.

SECTION 3

MATERIALS AND METHODS

SITE DESCRIPTION

The study site (Figure 1) was a 1920 ha stand of second-growth Douglas fir (Pseudotsuga menziesii) on Huckleberry Flats and adjacent areas located on the west slopes of the Cascade Mountains in westcentral Oregon. This stand had been harvested by clearcutting in the 1930s. Ground vegetation was predominantly salal Gaultheria sp; vine maple, Acer circinatum; Oregon grape, Berberis sp; and Rhododendron sp. Cottonwood, Populus sp, and red alder, Alnus rubra, were found in riparian areas.

Huckleberry Flats is classified primarily as land type 14 (Legard and Meyer, 1973) with very deep, slightly plastic to plastic soils derived from residual and colluvial materials. Surface soils are thin sandy loams and silt loams. Subsoils consist of thick silt loams, silty clay loams, and clay loams. Drainage is rapid in the surface soils and moderate to slow in the subsoils. In general the land type on Huckleberry Flats is typical of flats, benches, and terraces found in the Cascade Mountains of Oregon.

Elevation of the project area ranges from 800 m to 1100 m. The eastern edge has a mean slope of about 30% and the Flats area has a mean slope of about 10%.

Prior to the selection of areas to be fertilized, University of Washington personnel of the Regional Forest Nutrition Research Program initiated studies in 1969 to determine the growth response of Douglas fir to nitrogen fertilization in western Oregon and Washington. With information developed over four growing seasons (University of Washington, 1972; 1976), the United States Forest Service (USFS) identified Huckleberry Flats and Christy Flats as two major areas to be fertilized. Huckleberry Flats was selected for this study because it was large enough to incorporate the major portions of several perennial first, second, and third order streams draining the watershed, and had two streams proximate to the fertilized area which could be used as controls.

FERTILIZATION

The fertilization of Huckleberry Flats was conducted by the USFS, Willamette National Forest, Oakridge District during April, 1976. Agricultural grade urea prills, small pellets 1-2 mm diameter, were applied to the forest with a gondola-spreader carried by a helicopter. The application rate was 224 kg N/ha.

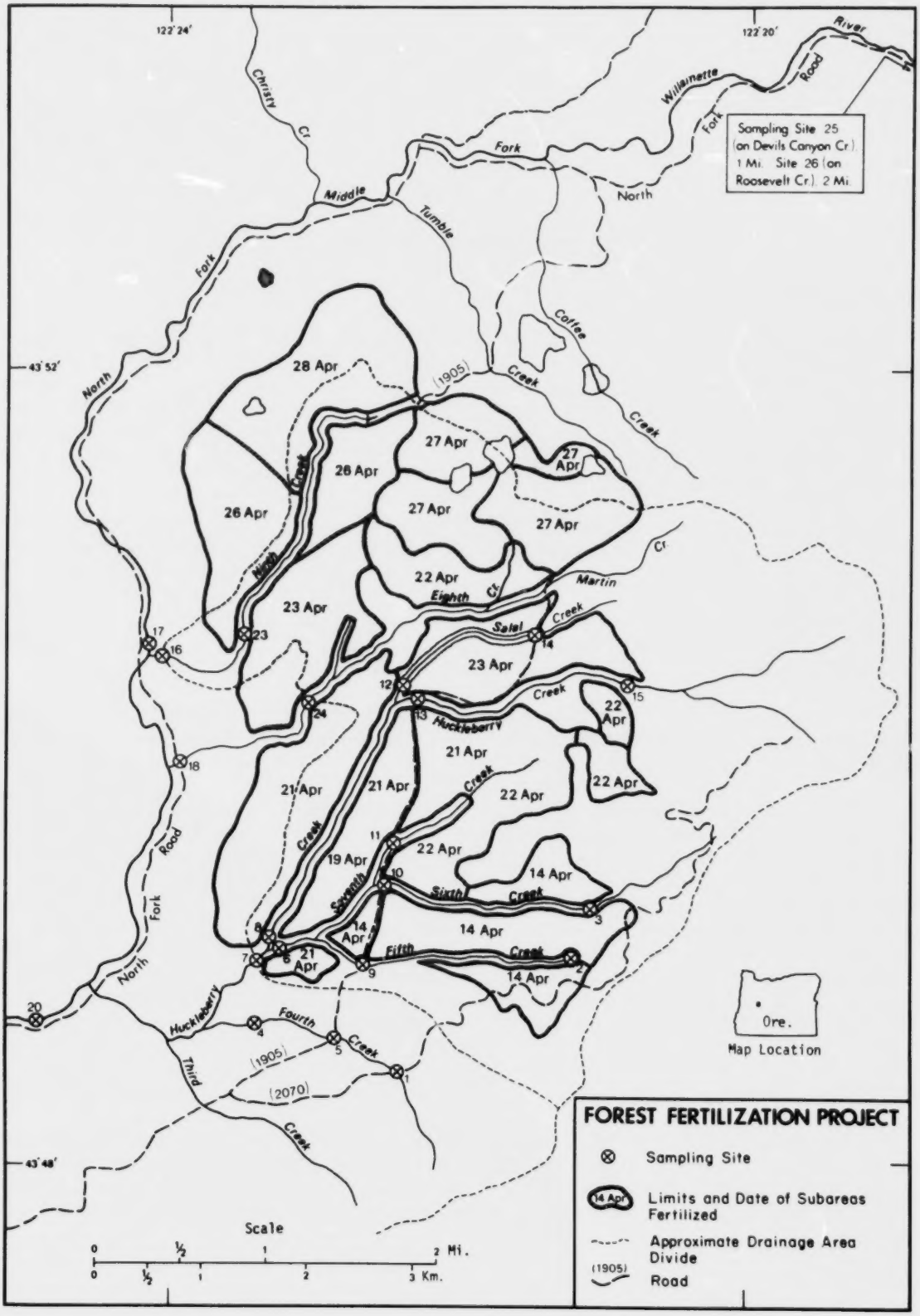


Figure 1. Map of fertilized sub-areas, dates of urea application, buffer zones, and sample stations.

During fertilization, sub-areas distinguishable from the air were fertilized individually with known amounts of urea to achieve the most accurate and uniform application to the total project area. Sub-areas, dates of urea applications, buffer strips, and sampling station locations are shown in Fig. 1.

Unfertilized buffer strips were maintained along each side of the major streams in the fertilized area. Width of the buffer strips was 45 m for the two largest streams, Huckleberry Creek and Seventh Creek, and 30 m for Fifth, Sixth, Salal, Eighth and Ninth Creeks. Fertilization was originally scheduled to begin 1 April 1976 but was postponed until 14 April because of heavy snow cover. Fertilization was intermittent during 14-28 April because of heavy rain and snow storms. Sampling stations were located on the upper and lower reaches of each stream in the fertilized area except for Eighth Creek, Ninth Creek, and Seventh Creek where access was not possible. The only access points for Stations 2 and 3 were located 0.3 km inside the fertilized area, and therefore could not be used as upstream controls.

Control streams originally selected for this study were Devils Canyon Creek, Station 25; upper Huckleberry Creek, Station 15; and Fourth Creek, Stations 1 and 4. Devils Canyon Creek was selected because it was similar in size to Huckleberry Creek and its watershed was completely separated from the fertilized area, reducing the possibility of contamination during fertilization.

Upper Huckleberry Creek, Station 15, was considered representative of Huckleberry Creek, Stations 8 and 13. This station was contaminated once by direct fall during fertilization; however, because the area affected was very small, and the effects short-term, Station 15 continued as a control. Fourth Creek, Stations 1 and 4, adjoins the fertilized area and was selected as a control because of its similarity to the smaller tributaries: Fifth, Sixth, and Salal Creeks. Unfortunately, during the fertilization of a plot south of Huckleberry Flats on 13 April, the area between Road 1905 and some point below Station 4 was uniformly contaminated; consequently, Station 4 could not be used as a control. On 14 April, Station 1 was contaminated and the effects persisted for an extended period of time. Because of uniform contamination above Station 4, it was used as an example of an unbuffered stream. Visual observations of prill density in this area suggested an application rate of one-third to two-thirds that used in the fertilized area. Because of this lower rate of application, the magnitude of effects found was considered equal to or less than that which might have occurred at the rate of 224 kg N/ha applied to the fertilized area.

Although it was not possible to obtain extensive antecedent characterization of the relationship between the control and the experimental streams, comprehensive characterization the month prior to the treatment suggested no major differences in streamwater chemistry.

PHYSICAL-CHEMICAL METHODS

Flow and Precipitation

Flow measurements were made with weirs and staff gages at each station. Weirs were calibrated by measuring flows with a pigmy-gurly meter at 8 widely different stage heights. With this information, rating functions were developed to calculate flow from observed stage heights at times of sample collection.

Precipitation was measured with 3 rain gages placed on the higher eastern edge of the project area and with 5 gages in the lower Flats area. Because vandals destroyed some of the gages during the study period, average values for the Flats area and higher slopes were not always based on the same number of samples.

Chemical Methods

Water samples were analyzed in the field for conductivity, pH, dissolved oxygen, and alkalinity. Subsamples were preserved with 4 mg $HgCl_2$/l, 25 ml concentrated HNO_3/l, or by cooling to 4°C (depending on the analytical requirements, APHA, 1975), and shipped to the Corvallis Environmental Research Laboratory for additional chemical analyses. United States Environmental Protection Agency methods (USEPA, 1974) were used for all chemical analyses except urea. Urea was hydrolyzed to ammonia by a modification of the Lienado and Rechnitz (1974) method, and the resultant ammonia was analyzed by conventional methods. The urea concentrations were calculated by subtracting the ammonia-N concentration before hydrolysis from the ammonia-N concentration after hydrolysis.

Periphyton samples were analyzed for chlorophyll *a*, phaeophytin, and ATP. Chlorophyll *a* and phaeophytin were determined using a modified method of Strickland and Parsons (1965) developed by Lorenzen (1967). Absorbance was measured with a dual beam scanning spectrophotometer at 750 and at 663 nm before and after acidification with two drops of 1N HCl. Absorbance values at 663 nm before (663) and after acidification (663 a) were corrected for absorbance at 750 nm and then used to calculate chlorophyll *a* and phaeophytin with the equations of Lorenzen. Because the chlorophyll was from a periphyton community these equations were modified to present results as weight/unit area:

$$\text{Chlorophyll } a,\ \text{mg/m}^2 = \frac{26.73\ [(663)-(663\ a)]\cdot\text{Extract volume (L)}}{\text{Slide Area (m}^2)\cdot\text{Cuvette Path Length (cm)}}$$

$$\text{Phaeophytin, mg/m}^2 = \frac{26.73\ [1.7\ (663\ a)-(663)]\cdot\text{Extract volume (L)}}{\text{Slide Area (m}^2)\cdot\text{Cuvette Path Length (cm)}}$$

Interferences resulting from a shift in the fucoxanthin absorption spectrum upon over-acidification have been noted for this method (Riemann, 1978). However, inspection of our sample absorption spectra, and the lower solvent molarity used (about 8×10^{-3} M HCl), suggests that interference from this carotenoid did not occur.

Samples for ATP analysis were extracted in the field within 2 hours after collection. Samples were first filtered through a 0.45 µm membrane filter, then immediately extracted with 10 ml of boiling Tris buffer, pH 7.75 (Cheer et al. 1974; Holm-Hansen and Booth, 1966). The extract was frozen with dry ice and stored at -25°C until analyzed. A refined luciferin-luciferase enzyme was used in the analysis. Emitted light was integrated for 1 minute with a commercial ATP photometer. Purified disodium ATP standard was used to prepare calibration curves each day ATP analyses were conducted. Standards were analyzed every 10 to 15 samples to detect any change in efficiency occurring during the period of analysis. ATP concentration in the extracts was converted to biomass by assuming an ATP content of 2.4 mg ATP/g dry weight organic matter (Weber, 1973). This method estimates the mass of viable organism only and values derived by this method are usually much lower than biomass estimates derived from gravimetric methods.

BIOLOGICAL METHODS

Fish Bioassay

Acute toxicity experiments were conducted using fingerling rainbow trout, Salmo gairdneri, from the Metolius Fish Hatchery, Camp Sherman, Oregon. Fish were placed in holding boxes, at Station 4 on Fourth Creek, after adjusting tank water to stream temperature. After a 24 hr acclimation in the holding boxes, 20 fingerlings about 8 to 10 cm long were placed in each of 2 test chambers located at each of the 10 stations selected for bioassays. The fish were then allowed to acclimate to the individual streams for two weeks prior to fertilization. They were fed trout pellets periodically throughout the experiment.

Macroinvertebrates

Three individual benthic samples of 0.09 m^2 were collected with a Surber sampler and composited (Hynes, 1970; USGS, 1977; USEPA, 1973). The sampling location at each station was changed each trip to avoid areas previously sampled. Sample material retained on a #30 mesh (0.5 mm) sieve was preserved in buffered 10% formalin. Invertebrates were sorted from the debris by hand picking, then preserved in 70% ethyl alcohol for counting and identification.

Drifting macroinvertebrates were collected with 0.30 m x 0.30 m x 1 m, 363 µm mesh Nitex nets. When possible the entire stream volume was passed through the nets. Drifting organisms were collected for 24 hrs to eliminate the effect of diurnal variations in numbers (Allan, 1978; Waters, 1972; Elliot, 1970). Samples removed from the nets were processed by the same procedures used for benthic samples. Organisms were enumerated and identified to the lowest taxonomic unit possible, usually genus or species. Organisms which could not be identified to this level were considered a unique bit of information during the calculation of species diversity.

Algal Assays

Algal assays were conducted according to the Algal Assay Bottle Test (USEPA, 1971). Water samples were collected in 4 l plastic bottles and stored

at 4°C. Samples were autoclaved and filtered, then cultured in triplicate sets as follows: streamwater without nutrient addition (control); 0.05 mg P/l; 1.0 mg N/l; 1.0 mg N/l + 0.05 mg P/l; and a micronutrient spike, 1X (AAM) medium concentration. Selenastrum capricornutum was used as the test alga.

Periphyton

Periphyton samples were collected from glass slides held in a floating acrylic plastic rack (Sladeckova, 1962; Hohn and Hellerman, 1963). Duplicate sets of racks were placed at each station for 4 and 8 week exposure periods. Four slides from each duplicate rack were collected per exposure period and duplicate slides were placed in each of two wide-mouth bottles containing streamwater. Growth on two of the four slides from each rack was removed, filtered with 0.45 µm membrane filters and extracted in boiling Tris for ATP. Growth on the other two slides was analyzed for chlorophyll a.

Decomposition

Decomposition of red alder leaves and Douglas fir needles was measured in duplicate at Stations 6 and 25 twice during the study. Dialysis chambers (McFeters and Stuart, 1972) with 8 µm membrane pore size (Figure 2) were used to isolate the substrate from the stream biota. Both red alder leaves and Douglas fir needles were collected from the study area during the fall season, dried at 35°C, and ground in a Wiley mill to pass through a #40 screen. Known amounts of substrate were then sealed in each dialysis chamber. Before being placed in the stream, each chamber was inoculated with 100 ml of streamwater taken with a 50 ml syringe from interstitial spaces of the top 2 cm of the bottom gravel. It was assumed that the heterotrophic population contained in this water and that which naturally occurred on the leaves would be of sufficient diversity and density to initiate a decomposer population within the chambers.

The chambers were placed in flow-through opaque plexiglas boxes to prevent algal growth (Figure 2). These boxes were then completely submerged, anchored to the stream bottom, and aligned so that the stream flow would force water continuously through the boxes. After two months the chambers were removed from the stream and the remaining residue collected. Within two hours, ATP was extracted from duplicate subsamples of the residue. The remainder of the residue was stored at 4°C until another set of duplicate subsamples could be filtered, dried at 105°C, and weighed. This information was used to determine total weight loss of the substrate and biomass of the heterotrophic population at time of collection.

Leaching experiments were also conducted on the same stock leaf material used in the decomposition study. Two grams of leaf substrate were placed in 200 ml of distilled water and allowed to stand at about 20°C for 24 hours. Subsamples were then filtered, dried at 105°C for 24 hr, and weighed to determine weight loss due to leaching. Weight loss due to decomposition was estimated by subtracting the estimated leaching loss from the total weight loss in each chamber. Because only initial and final weights could be measured in these experiments, it was assumed that weight loss conformed to the following exponential model (Petersen and Cummins, 1974):

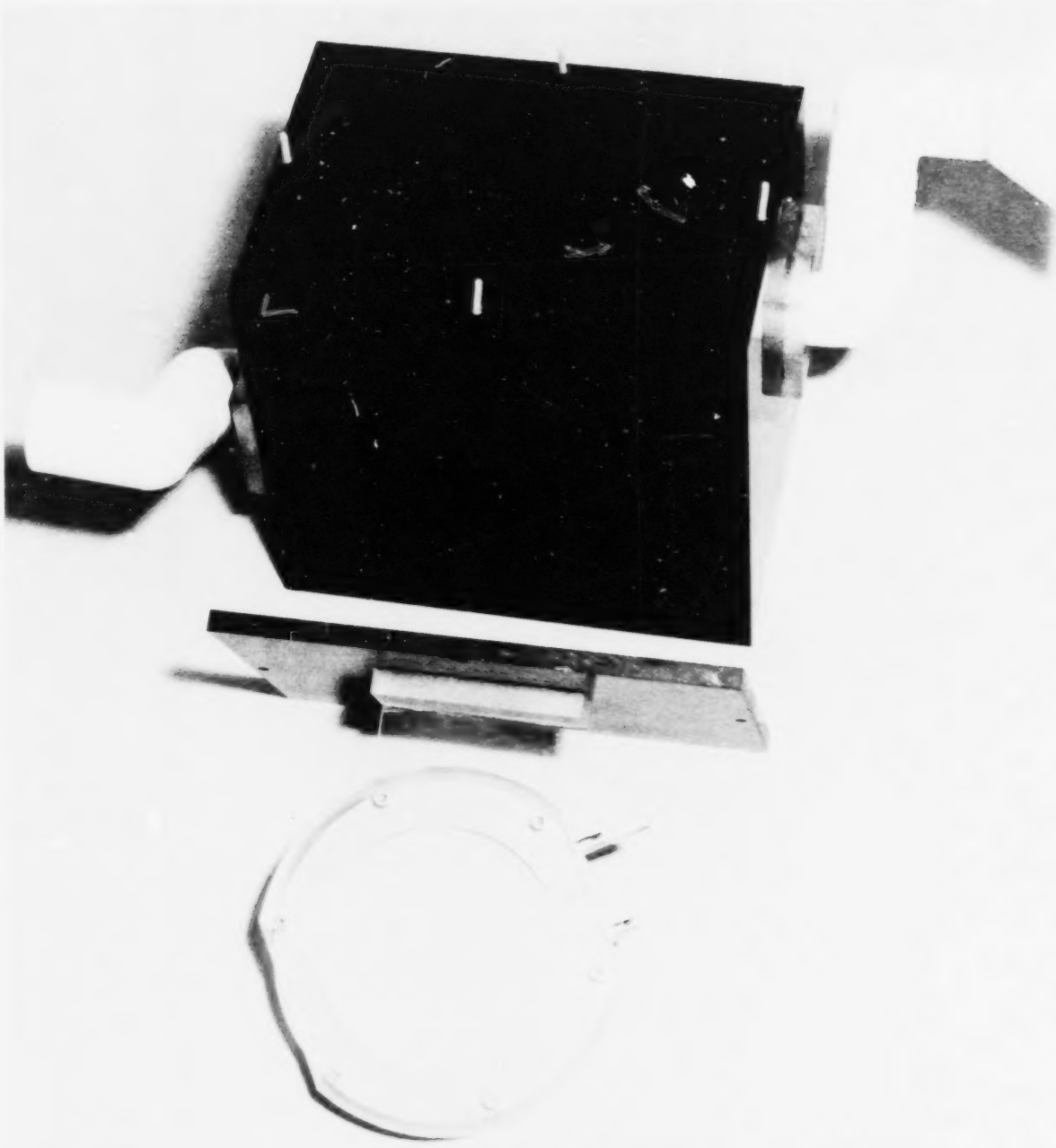


Figure 2. Opaque plexiglass box and dialysis chamber used to measure decomposition.

$$W_t = W_o\, e^{-kt}$$

W_t = Weight remaining at time (t)
W^t = Initial weight
k^o = Processing coefficient

Processing coefficients were calculated with the following equation:

$$\log_e \left(\frac{W_t}{W_o}\right)/t = -k$$

SAMPLE COLLECTION REGIMEN

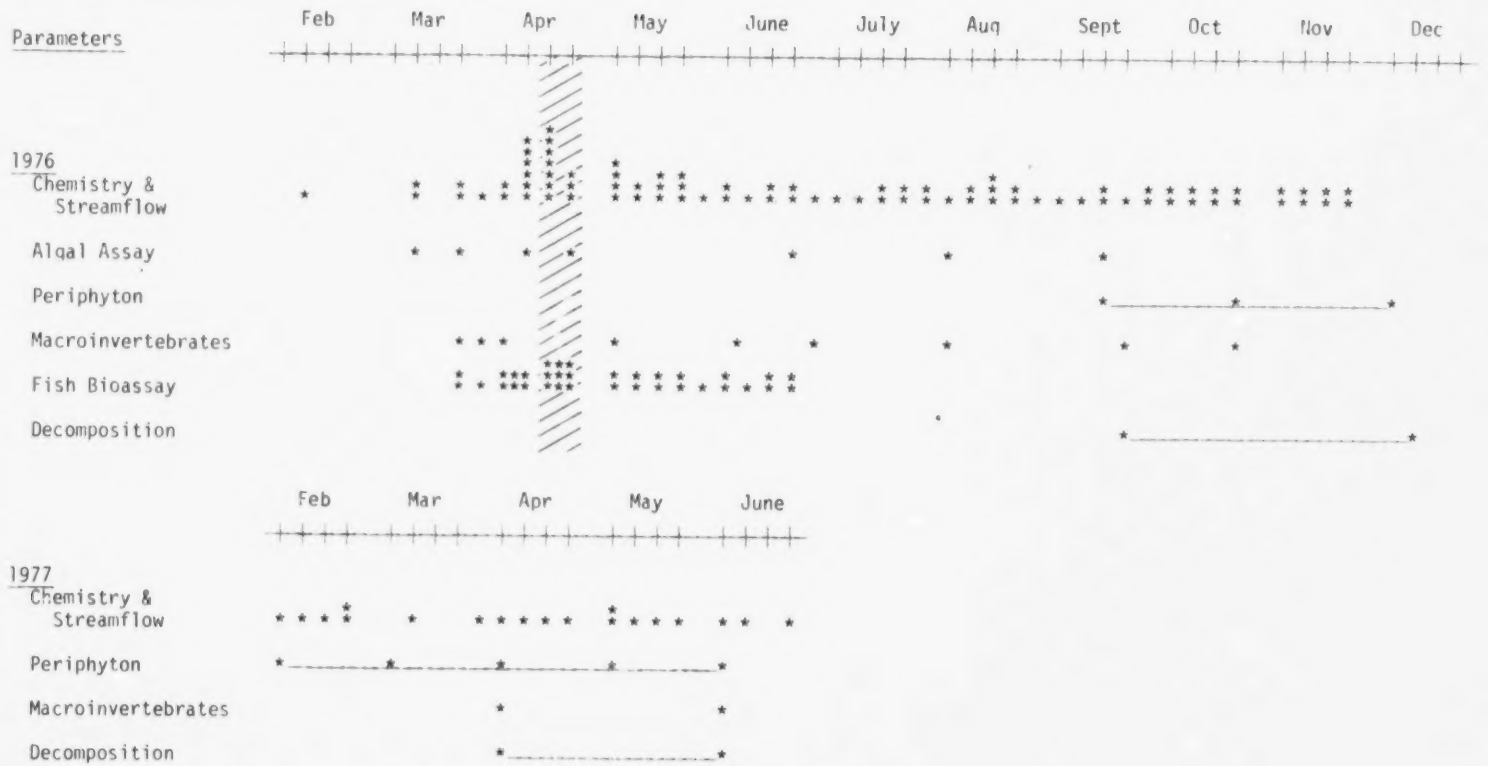
Sample collection frequencies and locations for all parameters measured are presented in Table 1, A and B. Each asterisk in Section B represents a sample collection event at stations listed in Section A.

TABLE 1. COLLECTION, LOCATION AND FREQUENCY OF PARAMETERS ANALYZED FOR EVALUATION OF FOREST FERTILIZATION AT HUCKLEBERRY FLATS

A Location of Parameters Sampled

Parameters	Stations Sampled
Chemistry & Streamflow	1, 2, 3, 4, 6, 8, 9, 10, 11, 12, 13, 14, 15, 23, 24, 25
Algal Assay	1, 4, 6, 8, 9, 10, 11, 12, 13, 15, 25
Periphyton	1, 6, 8, 9, 11, 12, 13, 15, 25
Macroinvertebrates	1, 4, 6, 8, 9, 10, 11, 12, 13, 15, 25
Fish Bioassay	1, 4, 6, 8, 9, 10, 11, 12, 13, 14
Decomposition	6, 25

B Frequency of Parameters Sampled



Fertilization period, 14-28 April, 1976, is indicated by the shaded area

SECTION 4

RESULTS AND DISCUSSION

PRECIPITATION AND STREAMFLOW

Precipitation data for Huckleberry Flats, adjacent slopes, and a NOAA weather station at the Oakridge Salmon Hatchery (USDC, 1976; 1977) 13 km southeast are presented in Table 2. Generally, the rainy season for the Pacific Northwest begins about October-November and lasts until early June. After June very little rainfall occurs until autumn. However during the 1976-1977 winter, there was a severe drought and precipitation was well below normal.

TABLE 2. PRECIPITATION AT HUCKLEBERRY FLATS AND A PROXIMATE NOAA SITE.

Month	Lower Flats Area (cm)	Upper Slopes Area (cm)	NOAA* Site (cm)	% of Monthly Mean NOAA Site (%)
Jan. 1976	ND	ND	20.1	117
Feb.	ND	ND	13.2	107
Mar.	ND	ND	13.9	112
Apr.	1.7	3.2	9.6	116
May	4.6	6.6	3.1	49
June	0.6	1.0	1.5	26
July	4.3	4.6	3.8	317
Aug.	4.3	5.1	11.9	900
Sept.	1.1	1.0	1.2	35
Oct.	1.0	1.1	4.3	62
Nov.	0.0	0.0	3.6	23
Dec.	ND	ND	3.1	17
Jan. 1977	ND	ND	5.0	28
Feb.	2.7	2.2	5.0	40
Mar.	22.3	28.7	14.3	117
Apr.	5.3	4.8	4.1	50
May	19.6	23.0	13.7	216
June	2.0	2.3	0.7	12

* Oakridge Salmon Hatchery Located 13 km S.E. of Huckleberry Flats.

Elevation = Lower Flats Area ∿ 800 m
Upper Slope Area ∿ 1100 m
Salmon Hatchery ∿ 600 m

ND = no data available.

Although precipitation at the NOAA site was quite different than that at Huckleberry Flats, it is included in Table 2 to compare the 1976-1977 winter to an average winter derived from a long-term data base. During September-February 1976, when precipitation is usually highest, rainfall was 29% of the mean at the NOAA site and 76% of the mean for the total study period.

Although extensive antecedent precipitation information at Huckleberry Flats is not available for comparison, trends were similar to those at the NOAA site. Rainfall at Huckleberry Flats declined during the spring, increased during July and August, and then remained very low to the end of the study except for short periods in March and May.

Stream flow (Figure 3) reflected the extent of the drought at all stations measured. Flow declined from the start of the study through the 1976-1977 winter, then increased sharply. Surface flow at Stations 2 and 10 completely stopped from late summer through winter. Although there was generally a declining hydrograph throughout the first year, flows did increase during periods of higher precipitation. Flows were higher the second year during March to June and peak values corresponded to increased rainfall.

These data suggest that the streams evaluated for this study fall into three general groups. Huckleberry Creek, Stations 8, 13, 15, and Devils Canyon Creek consistently exhibited the highest flows (10^2 to 10^3 l/sec). Huckleberry Creek was unique because a very high proportion of its flow originated above the fertilized portion of the watershed. Seventh Creek, Stations 6, 11; Eighth Creek, Station 24; and Ninth Creek, Station 23; had lower and more variable flows (10^0 to 10^2 l/sec) than did Huckleberry Creek and Devils Canyon Creek. Fourth, Fifth, Sixth and Salal Creeks generally had the lowest flows ranging from 0 to 10^2 l/sec.

STREAM CHEMICAL COMPOSITIOON

Average chemical composition of the streams before, during and after fertilization is presented in Table 3. The "before" average represents about one month prior to fertilization and comprises the smallest number of samples. The "during" average represents all data collected during and two weeks after the last date of fertilization in the upstream watershed. These data include the effect of direct application of urea to the stream surface and riparian area. The "after" average is derived from samples collected during the remaining period of the study.

In general the streams were typical pristine Cascade mountain streams (Fredriksen et al. 1975) characterized by soft waters with low concentrations of dissolved materials. Although the buffering capacity of these waters was low as indicated by the alkalinity, the pH varied little throughout this study. Values in Table 3 were determined by first converting pH to hydrogen ion concentrations, calculating the mean (H) then converting this to pH. Mean values of pH were similar for all stations and periods, and did not appear to be affected by fertilization.

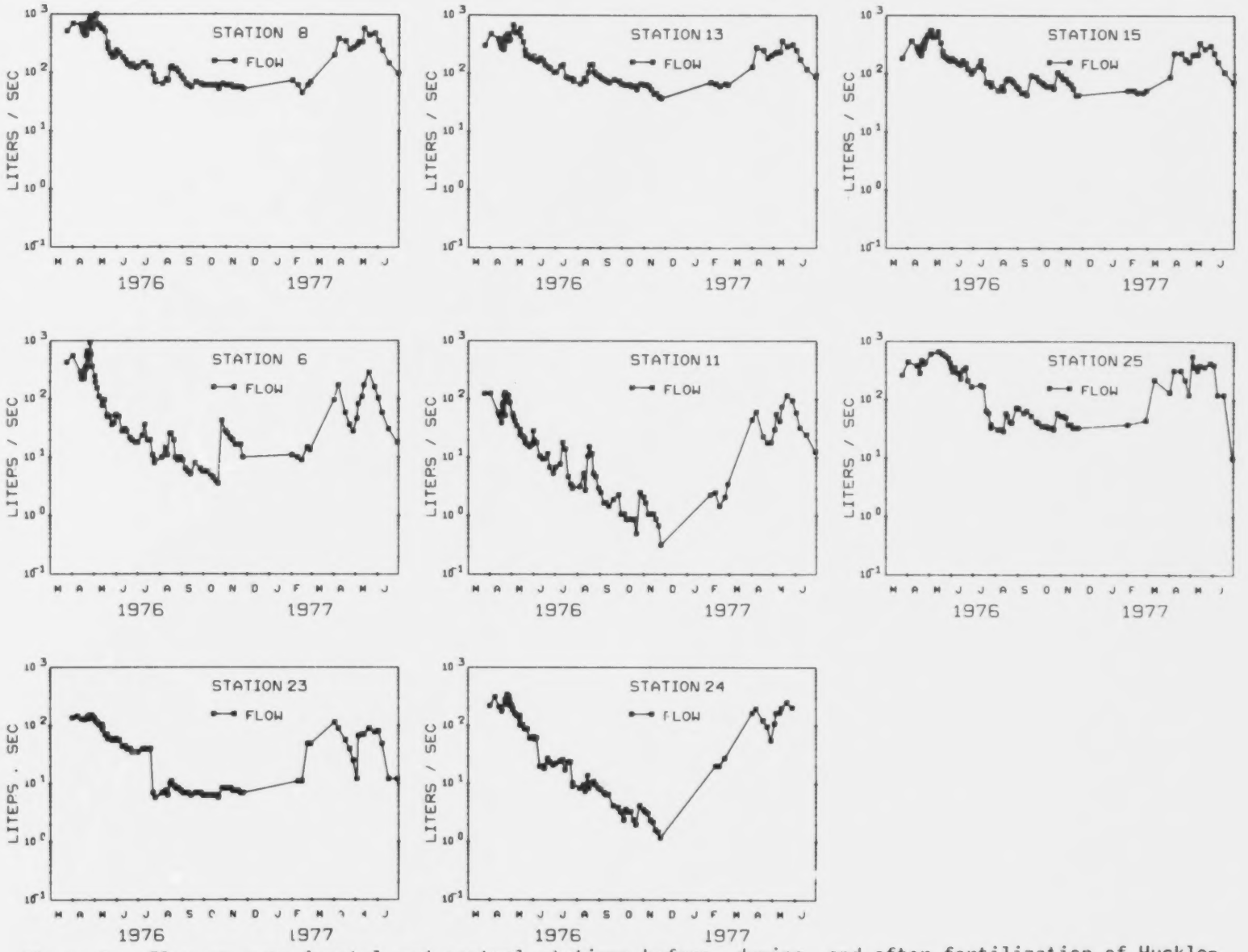


Figure 3. Flow at experimental and control stations before, during, and after fertilization of Huckleberry Flats.

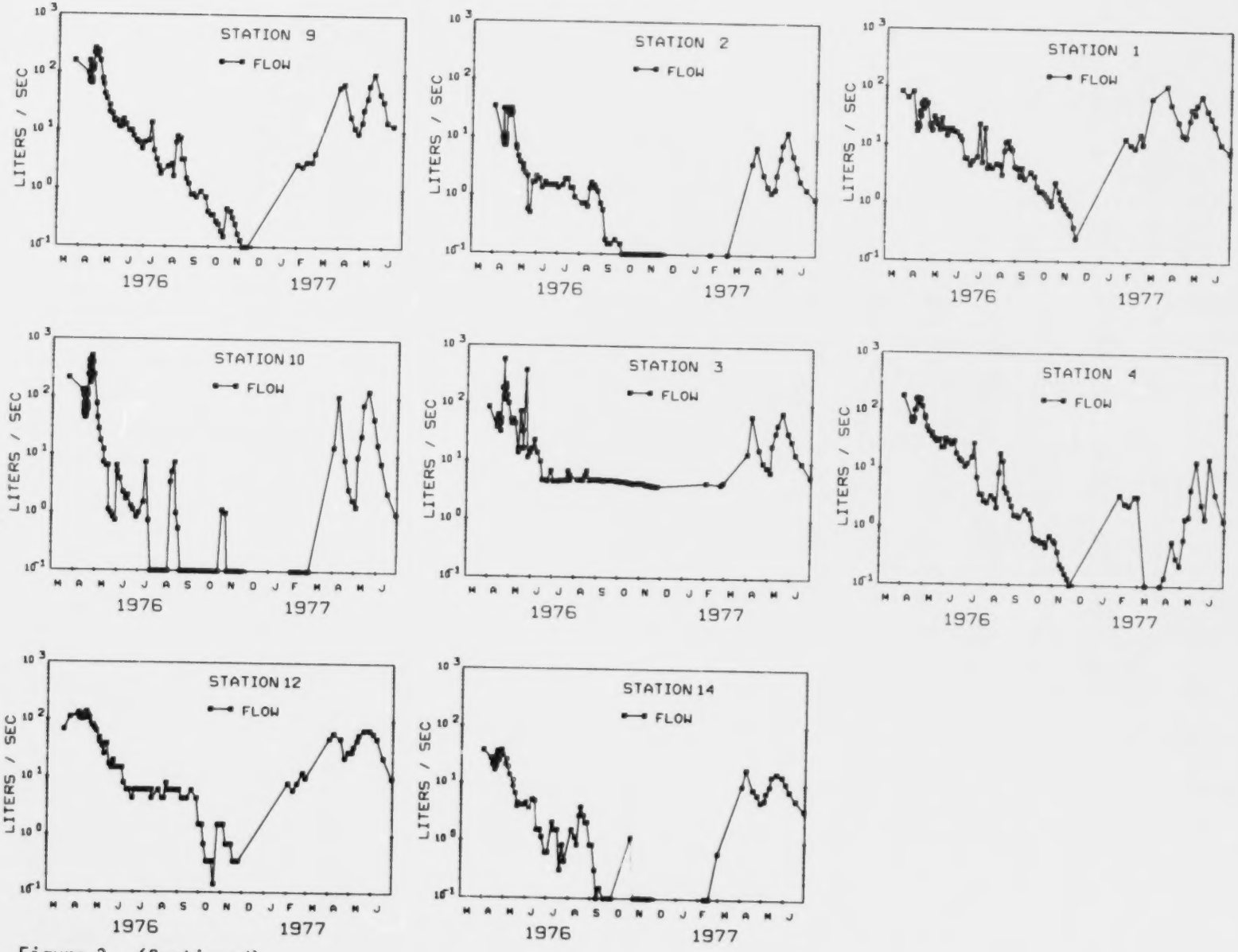


Figure 3. (Continued)

TABLE 3. AVERAGE STREAM CHEMICAL COMPOSITION IN EXPERIMENTAL AND CONTROL STREAMS BEFORE, DURING, AND AFTER FERTILIZATION OF HUCKLEBERRY FLATS

		Devils Creek	Huckleberry Creek			Salal Creek		Fourth Creek		Fifth Creek		Sixth Creek		Seventh Creek		Eighth Creek	Ninth Creek
Station #		25	8	13	15	12	14	4	1	9	2	10	3	6	11	24	23
Spec. Conductance (μmhos/cm)	Before	27.5	27.2	32.6	31.4	15.4	16.3	19.2	20.2	18.0	19.5	28.9	29.7	32.5	18.9	18.8	16.8
	During	26.0	25.0	28.1	31.2	14.9	18.9	20.7	21.2	18.4	19.8	27.3	30.2	21.5	19.1	18.1	16.5
	After	28.0	36.9	37.2	37.6	28.0	25.0	29.3	28.5	27.6	25.2	36.8	34.1	30.6	27.0	23.8	22.6
Total Hardness (mg $CaCO_3$/l)	Before	10.4	9.5	11.6	12.4	5.3	6.0	5.6	5.2	5.2	6.3	10.0	11.0	7.0	5.4	6.0	6.2
	During	9.7	11.5	11.4	11.8	5.7	6.8	5.9	5.8	5.6	6.3	10.4	10.8	6.9	6.5	6.9	6.4
	After	13.0	15.3	16.3	16.0	12.8	8.7	9.7	8.5	10.0	8.6	14.7	10.8	10.5	9.5	10.3	10.1
Alkalinity (mg $CaCO_3$/l)	Before	12.7	11.9	13.7	15.1	7.1	7.4	6.9	8.4	7.4	8.3	13.2	13.4	8.7	7.7	7.8	6.8
	During	-	12.1	14.9	15.3	6.4	7.8	8.4	8.7	8.2	8.3	13.5	13.8	9.3	9.3	-	-
	After	14.1	16.7	16.7	18.4	13.6	12.1	12.4	11.9	12.2	12.1	17.0	14.6	13.5	12.3	15.1	12.7
Total Inorganic -C (mg C/l)	Before	1.0	1.1	1.2	1.3	.9	.9	1.0	1.2	1.0	1.0	1.4	1.0	1.1	1.0	1.0	1.0
	During	.7	.8	.9	.8	.8	.6	.7	.7	.8	.8	.9	1.1	.8	.8	.8	.8
	After	1.0	1.0	1.1	1.2	1.2	1.0	1.1	1.0	1.0	1.0	1.1	1.0	1.0	1.0	1.0	1.0
Total Organic -C (mg C/l)	Before	.2	.3	.3	.2	.2	.2	.9	.8	.5	.2	.5	.5	.6	.2	.6	.9
	During	.6	.5	.8	.6	.7	.5	.9	1.0	.7	.3	.9	.7	.5	.5	2.1	1.7
	After	.7	.8	1.0	.8	.8	.6	1.9	1.6	1.5	.8	1.1	1.1	1.2	1.0	1.4	1.4
Total Kjeldahl -N (mg N/l)	Before	.087	.077	.047	.050	.054	.161	.100	.053	.050	.075	.063	.075	.067	.050	.050	.063
	During	.063	.095	.472	2.379	.474	.704	.167	.086	.092	.205	.299	.296	.119	.298	.696	.056
	After	.087	.066	.064	.065	.066	.077	.120	.091	.084	.084	.072	.085	.089	.077	.146	.080
Ammonia (mg N/l)	Before	.005	.005	.005	.005	.005	.005	.007	.006	.005	.007	.006	.005	.005	.005	.005	.005
	During	.005	.005	.006	.005	.006	.007	.007	.005	.005	.007	.006	.011	.005	.010	.005	.005
	After	.012	.006	.006	.006	.008	.010	.011	.008	.009	.007	.008	.008	.008	.008	.011	.009
Nitrate-Nitrite (mg N/l)	Before	.006	.005	.005	.005	.006	.006	.011	.013	.007	.005	.006	.005	.006	.005	.005	.005
	During	.005	.007	.013	.005	.014	.010	.026	.009	.007	.008	.010	.007	.006	.007	.011	.005
	After	.007	.008	.010	.006	.007	.020	.032	.015	.009	.017	.011	.016	.008	.007	.019	.019
Urea (mg N/l)	Before	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
	During	.020	.059	.414	1.427	.565	.940	.091	.020	.047	.129	.347	.218	.066	.361	.187	.117
	After	.020	.020	.020	.020	.020	.020	.033	.025	.023	.022	.025	.023	.020	.020	.024	.020
pH	Before	6.7	6.5	6.4	6.4	6.2	6.2	6.3	6.5	6.2	6.2	6.3	6.7	6.3	5.9	6.3	5.8
	During	6.3	6.3	6.4	6.5	6.1	6.1	6.0	6.3	6.2	6.2	6.3	6.4	6.2	6.0	6.3	6.0
	After	6.5	6.6	6.7	6.7	6.6	6.3	6.5	6.6	6.2	6.3	6.5	6.4	6.5	6.4	6.3	6.3
Total Phosphate (mg P/l)	Before	.014	.010	.015	.013	.011	.010	.010	.010	.010	.010	.010	.010	.010	.014	.012	.013
	During	.010	.011	.010	.011	.010	.010	.012	.013	.011	.012	.011	.013	.013	.010	.010	.010
	After	.012	.013	.011	.010	.011	.010	.011	.012	.014	.012	.011	.013	.016	.012	.011	.012
Orthophosphate (mg P/l)	Before	.008	.005	.005	.005	.005	.005	.005	.007	.005	.005	.006	.005	.005	.005	.005	.005
	During	.005	.005	.005	.005	.005	.005	.005	.006	.005	.005	.006	.005	.005	.005	.005	.005
	After	.006	.005	.005	.005	.005	.005	.005	.006	.005	.005	.005	.005	.005	.005	.005	.005
Calcium (mg Ca/l)	Before	3.1	2.9	3.5	4.0	1.5	1.6	1.8	1.9	1.4	1.6	2.8	3.0	1.8	1.6	1.6	1.3
	During	2.9	2.9	3.5	3.6	1.3	1.5	1.5	1.6	1.6	1.6	3.0	3.1	1.9	1.7	1.7	2.0
	After	3.7	4.7	5.0	5.0	4.0	2.3	2.3	2.3	2.4	2.1	4.0	2.8	2.6	2.3	2.6	2.6
Sodium (mg Na/l)	Before	1.5	1.7	1.9	1.9	1.1	1.1	1.7	2.0	1.3	1.3	1.9	1.8	1.5	1.3	1.6	1.0
	During	1.5	1.6	1.8	1.7	1.0	1.1	1.6	1.8	1.3	1.2	1.8	1.9	1.5	1.4	1.2	1.2
	After	2.1	2.3	2.3	2.3	2.0	1.6	2.4	2.7	1.9	2.0	2.5	2.3	2.1	2.1	1.9	1.8
Potassium (mg K/l)	Before	.2	.3	.2	.3	.2	.2	.5	.6	.4	.4	.4	.5	.4	.3	.3	.3
	During	.2	.2	.2	.2	.1	.2	.4	.4	.3	.2	.4	.3	.3	.3	.3	.2
	After	.3	.2	.2	.2	.2	.2	.4	.4	.3	.3	.3	.3	.3	.3	.3	.3
Magnesium (mg Mg/l)	Before	.6	.7	.6	.6	.5	.6	.6	.6	.6	.7	.8	.8	.7	.6	.5	.6
	During	.6	.7	.6	.6	.5	.6	.5	.5	.7	.7	.9	.8	.7	.5	.6	.8
	After	.9	.8	.8	.8	.8	.8	.9	.7	.9	.9	1.1	.9	.9	.8	.8	.9
Total Cation* (mg/l)	Before	5.6	5.8	6.4	6.9	3.4	3.7	4.7	5.2	3.9	4.1	6.0	6.1	4.6	4.1	4.1	3.3
	During	5.2	5.5	6.3	6.2	3.1	3.5	4.2	4.4	4.0	3.9	6.2	6.2	4.6	4.2	3.9	4.5
	After	7.1	8.3	8.6	8.7	7.4	5.1	6.2	6.3	5.7	5.3	8.2	6.4	6.1	5.7	5.8	5.9

* Total Cation = The sum of the Ca, Na, K, and Mg concentrations.

Average total cation concentrations were higher in the "after fertilization" period in the controls as well as the experimental stations, suggesting that the increase was not due to cation exchange caused by fertilization, as noted by others (Aubertin et al. 1973; Cole and Gessel, 1963), but was probably due to other factors.

Nutrient concentrations in the streams remained low throughout the study. Average total phosphorus for all streams ranged between the analytical limit (0.010 mg P/l) and 0.016 mg P/l. Orthophosphorus remained at or near analytical limits at all stations with average values of 0.005-0.008 mg P/l. Average urea and Kjeldahl nitrogen (TKN) were higher during the fertilization phase at all experimental stations, when average urea-N and TKN ranges were 0.020-1.429 and 0.056-2.370 mg N/l, respectively. The high nitrogen concentrations at Station 15 during fertilization were due to direct contamination of the stream at the time of one sample collection. If the results of this sample are omitted, average urea-N and TKN are very near the analytical limits of 0.022 and 0.100 mg/l, respectively.

Average nitrate-nitrite and ammonia-nitrogen were at or near analytical limits during all three periods at both the control and experimental stations. In medium to low flow streams, average nitrate-nitrite nitrogen was slightly higher in the "during" and "after" fertilization periods than "before."

Detailed information on urea, ammonia, nitrate-nitrite, and TKN is presented in Figures 5, 6, 7, and 8.

Urea concentrations (Figure 4) were below analytical limits at all stations just prior to fertilization and from November 1976 through June 1977. During fertilization all experimental stations had short periods of increased urea concentration. These high values were the result of inadvertant urea application to the stream proper and proximate riparian areas.

During fertilization, two of the control streams, upper Huckleberry and Fourth Creeks, were contaminated. Because the impact at Station 15 was minimal, it was retained as a control. Fourth Creek was contaminated to a much greater extent and could not be used as a control, but was used as an example of a stream without buffer strips because urea contamination was uniform throughout its watershed. Also, because the application rate was only one-third to two-thirds the 224 kg N/ha applied to the fertilized area, the magnitude of effects was considered equal to or less than those which might have occurred at the higher application rate.

Following fertilization, urea concentrations at Huckleberry Creek Stations 13 and 8 generally remained below analytical limits. However, Seventh Creek Station 11, also buffered by 45 m strips, showed extended periods of increased urea concentrations during the post-fertilization period. This difference was probably due to a combination of the direct fertilization of the headwater streams of Seventh Creek, which are mainly located in the fertilized area, and the greater proportion of flow in Huckleberry Creek originating outside the fertilized area. Because the number and extent of buffer zone violations were similar in both streams, as shown by urea peaks during

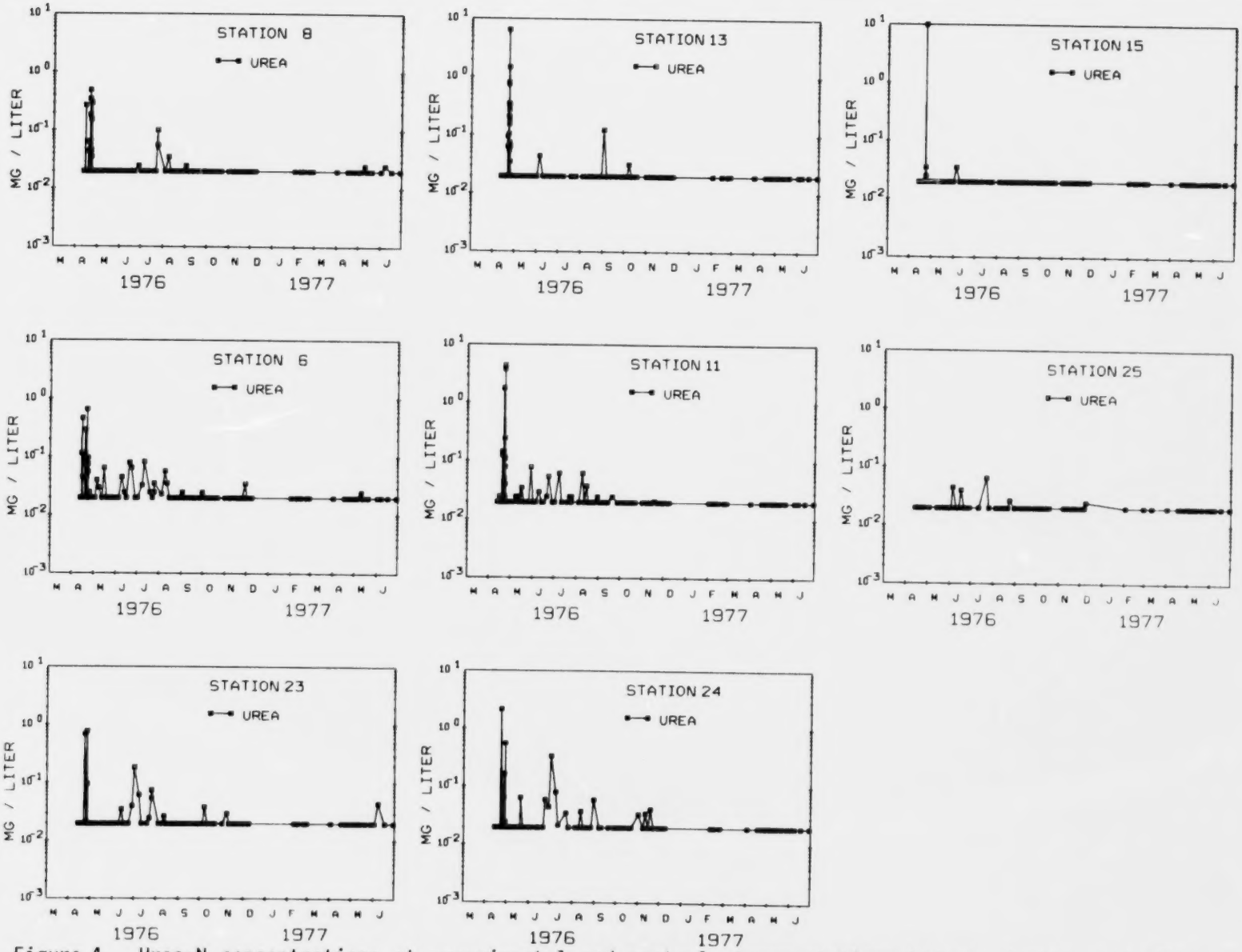


Figure 4. Urea-N concentrations at experimental and control stream stations before, during, and after fertilization of Huckleberry Flats.

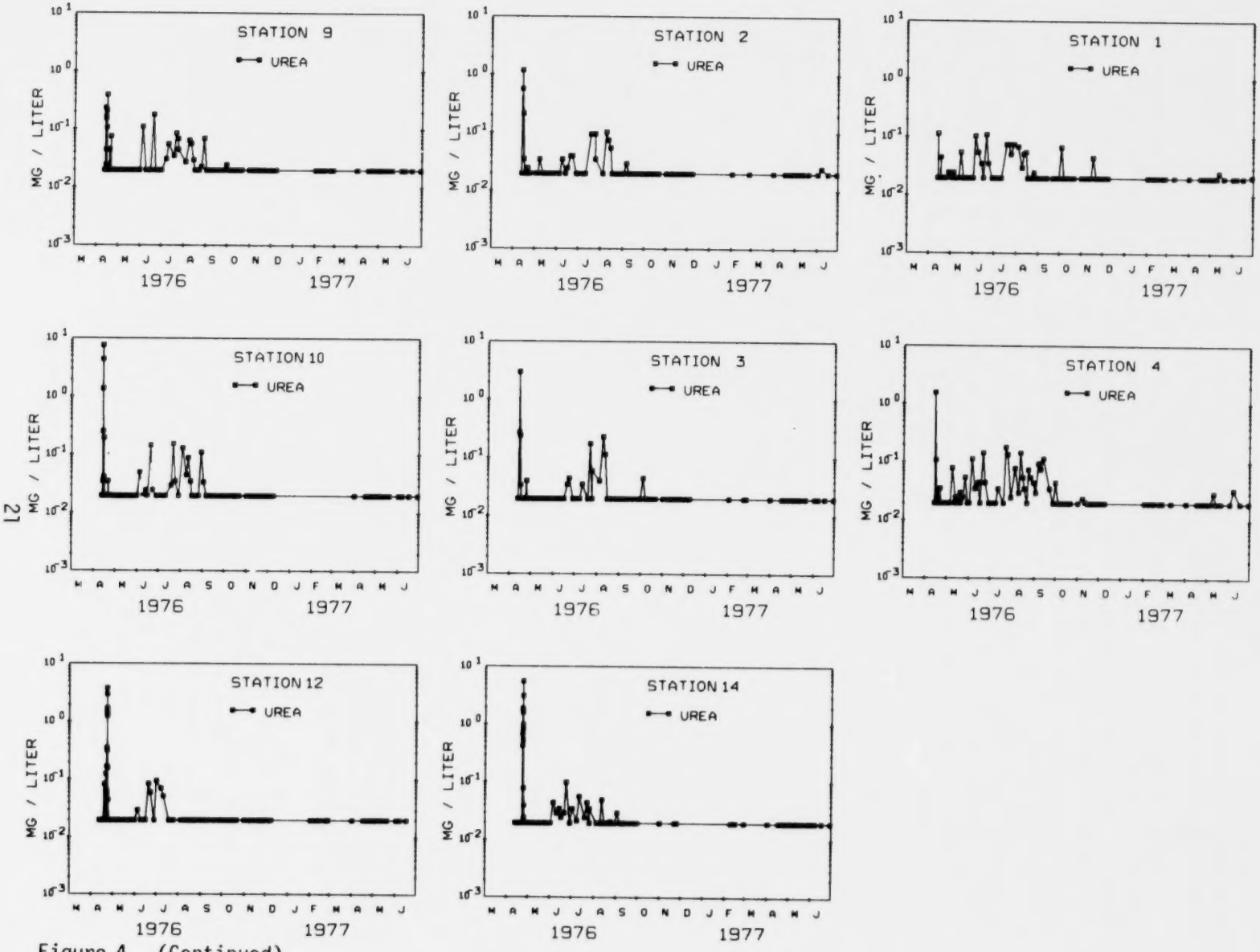


Figure 4. (Continued)

the fertilization period, it is unlikely that these violations were responsible for differences which occurred between these two streams.

Urea concentrations in streams buffered by 30 m unfertilized strips were generally higher for more extended periods than were Seventh or Huckleberry Creeks. The flows at Eighth and Ninth Creeks were similar to those at Station 11 and were the highest of the streams buffered by 30 m strips. Urea concentrations in these two streams were elevated for more extended periods than those at Station 11 and were less than those in Fifth and Sixth Creeks. Lower Salal Creek Station 12 had the lowest urea concentrations of streams with 30 m buffer strips. Higher urea concentrations found in streams buffered by 30 m strips appear to be the result of narrower buffer zones and lower dilution and, again, not due to the number and extent of buffer zone violations. Fourth Creek Station 4 had higher urea concentrations for more extended periods than all other stations even though loadings were less than 224 kg/ha. This was due to the absence of buffer strips to restrict the transport of nitrogen to the streams (Fredriksen et al. 1975).

Ammonia N increased at all experimental stations except 23 and 24 during the fertilization period (Figure 5). Ammonia concentrations in the controls generally remained low during and following fertilization; however, concentrations in Devils Canyon Creek were generally higher than those in Huckleberry Creek. These higher values may have been due to decomposition of tissue sloughed from the nitrogen-fixing symbionts associated with riparian red alder (Moore, 1975a, b; Franklin et al. 1968) which were common near Station 25, but not as numerous along Huckleberry Creek. Urea contamination is unlikely because the drainage basin of Devils Canyon Creek is well removed from the fertilized area. Because of this additional ammonia source and its variability among stations, no conclusions can be drawn about the effect of fertilization on ammonia concentrations in the experimental streams. In general, concentrations were greatest at all stations during June-November 1976, and increased slightly again during May-June, 1977.

Nitrate-nitrite concentrations increased sharply at all experimental stations during the fertilization period (Figure 6), as did urea, apparently as a result of buffer zone violations. In both control stations, NO_3-NO_2 generally remained below analytical limits throughout the study. This suggests that nitrogen input from the red alder did not significantly affect NO_3-NO_2 concentrations, and the increased concentrations found in the experimental streams were the result of fertilization.

During the 1976 post-fertilization period, NO_3-NO_2 concentrations in Huckleberry Creek were similar to those in the controls and less than all other experimental stations. Nitrate-nitrite concentrations in Seventh Creek, which was also buffered by 45 m strips, were greater than those in Huckleberry Creek and less than most stations with 30 m buffer zones. Concentrations in streams buffered by 30 m strips were elevated for extended periods and were similar to each other. Nitrate-nitrite concentrations were highest for more extended periods in Fourth Creek than in all other creeks studied. This, again, is a response to the lack of unfertilized buffer zones to impede the transport of nitrogen to the stream.

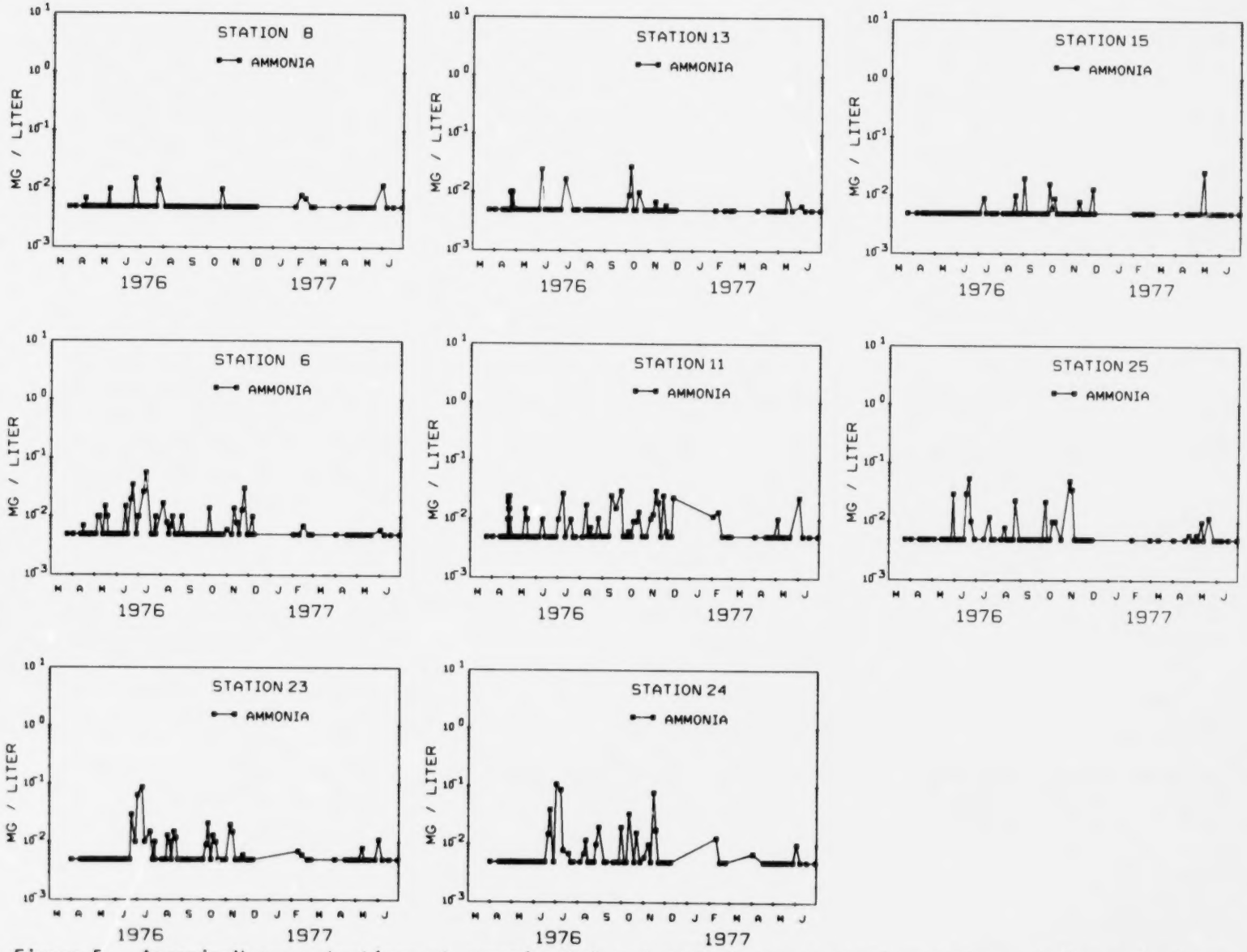
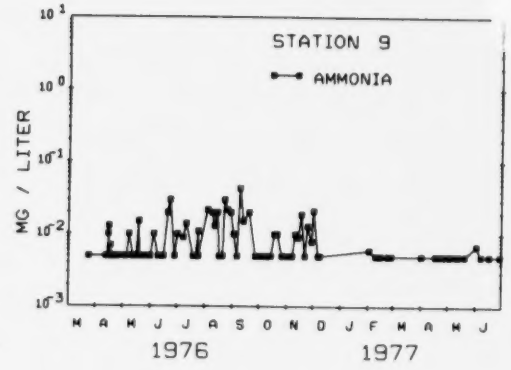
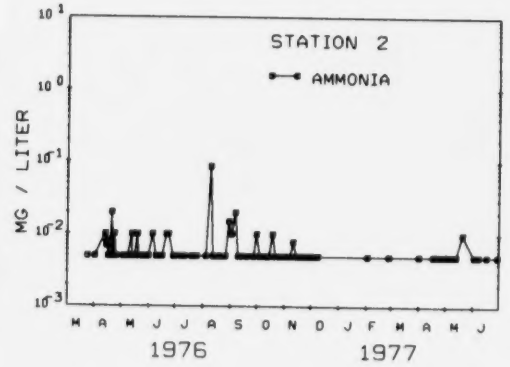
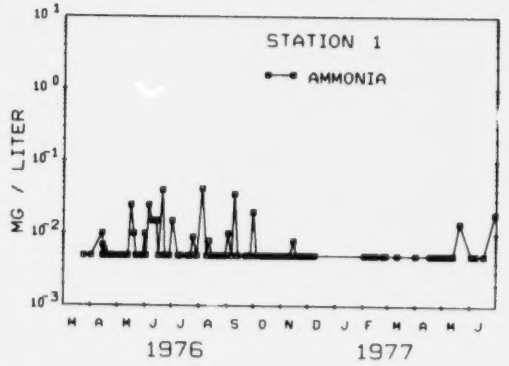
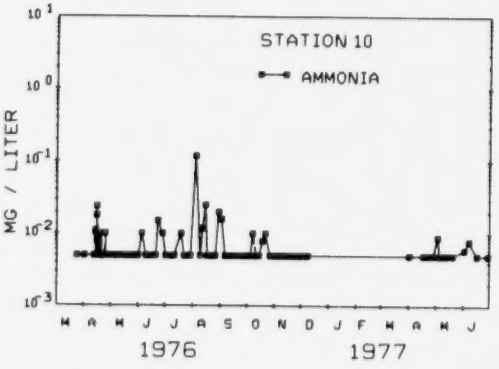


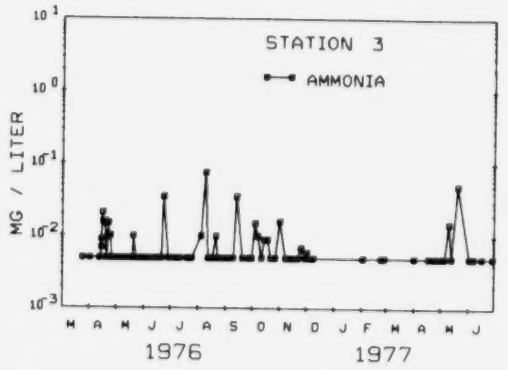
Figure 5. Ammonia-N concentrations at experimental and control stream stations before, during and after fertilization of Huckleberry Flats.

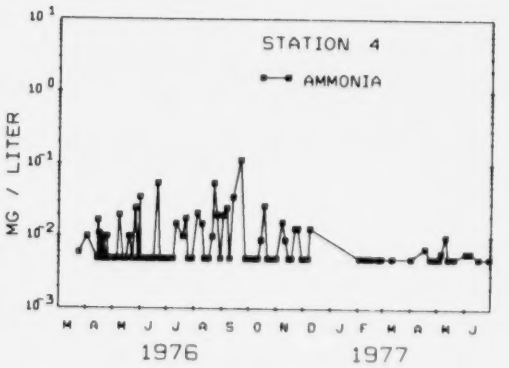


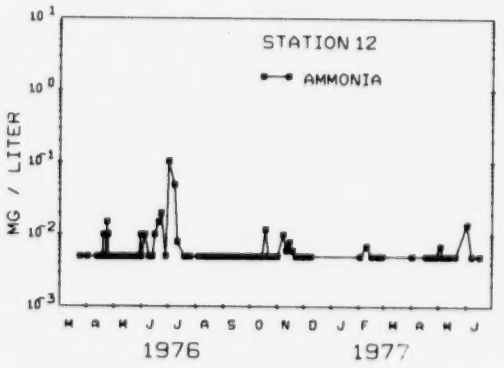


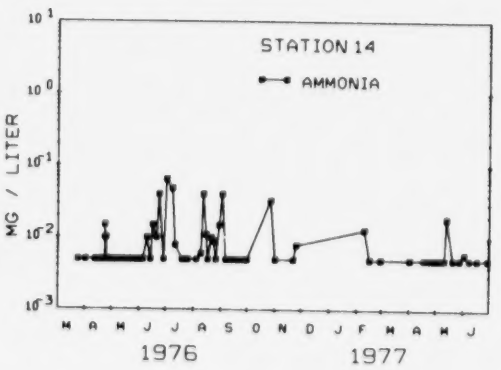












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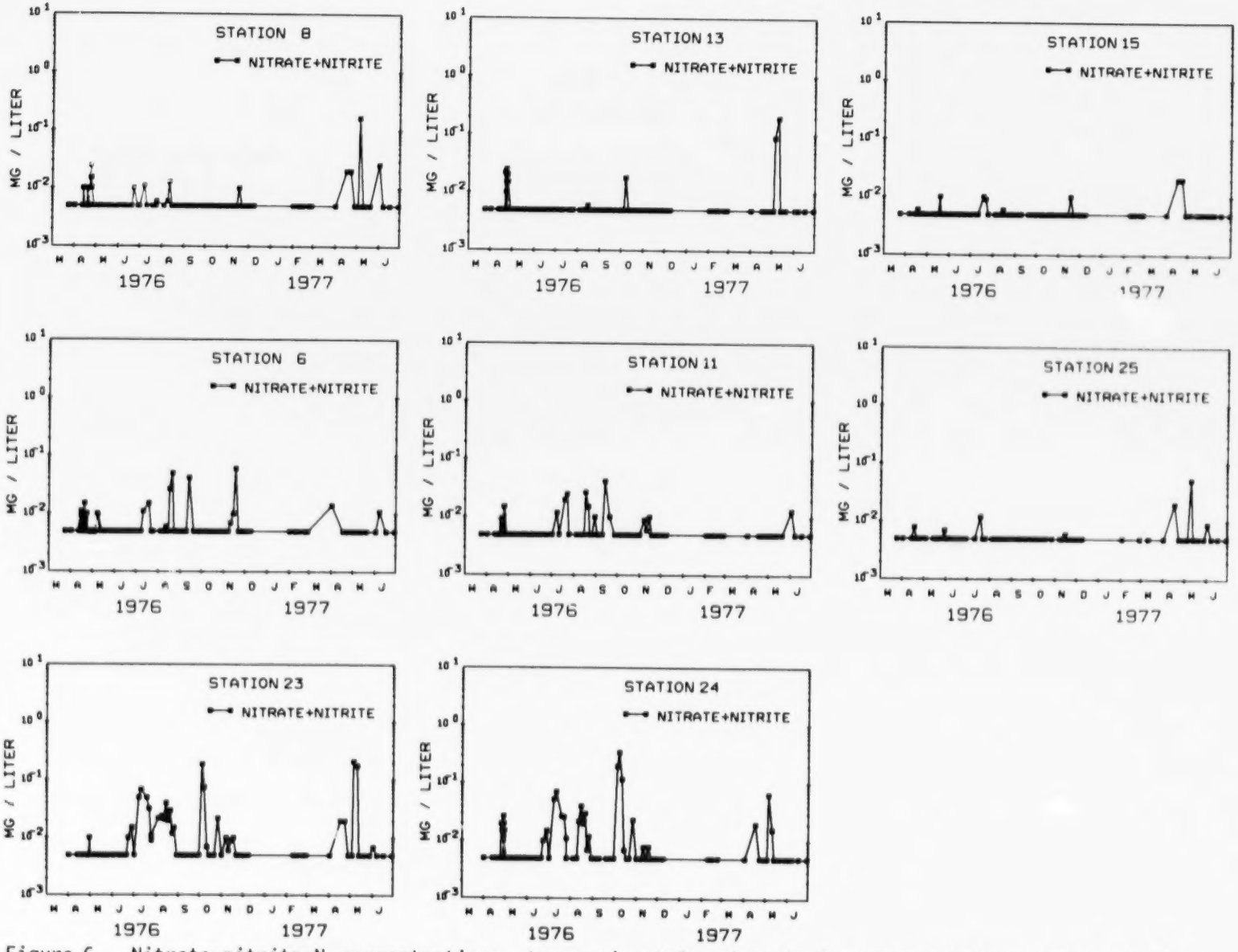

Figure 6. Nitrate-nitrite-N concentrations at experimental and control stream stations before, during and after fertilization of Huckleberry Flats.

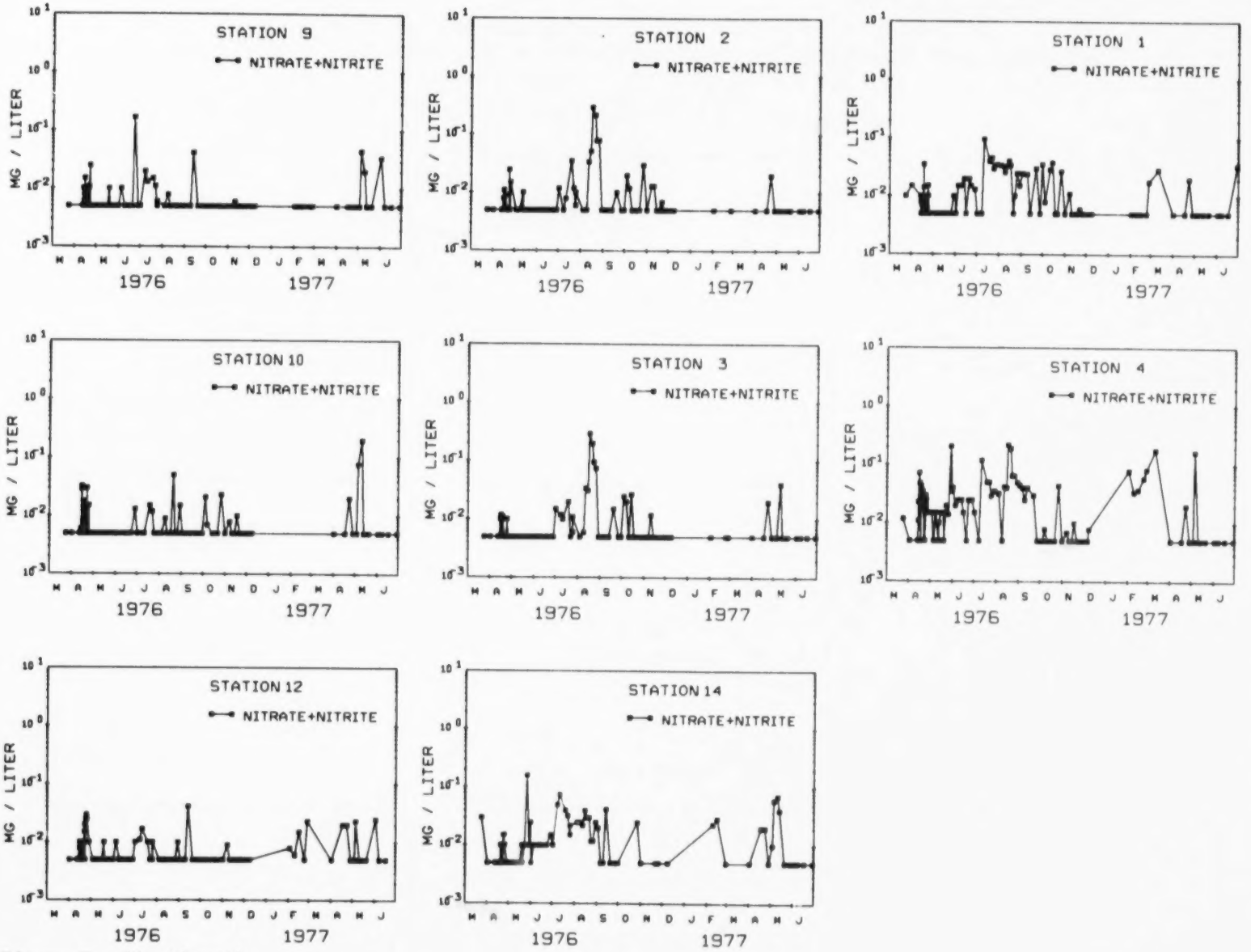

Figure 6. (Continued)

During the second year, NO_3-NO_2 was the predominant inorganic nitrogen form in the stream. Similar results have been found by others in the Pacific Northwest (Moore, 1975b; Fredriksen et al. 1975).

Total Kjeldahl nitrogen concentrations in Seventh Creek and all 30 m buffered streams were similar to one another and greater than those in Huckleberry Creek (Figure 7). Highest TKN concentrations occurred during fertilization and were due to the increased urea concentrations. Following fertilization, TKN decreased at all experimental stations. After August, it consisted primarily of organic compounds other than urea. Differences between concentrations upstream and downstream stations as well as between control and experimental stations were not great enough to suggest the increased leaching of organic nitrogen which Ogner (1972a; 1973) observed following fertilization.

These data suggest that fertilization did increase the nitrogen content in the experimental streams, and that the 45 m unfertilized buffer strips combined with the high dilution factor were effective in maintaining low nitrogen concentrations in Huckleberry Creek. The combination of unbuffered headwater streams and lower dilution reduced the effectiveness of the 45 m buffer strips at Seventh Creek Station 11. The 30 m buffer strips, although not as effective as was the 45 m zone for Seventh Creek, were more effective than no buffer strips, as demonstrated at Fourth Creek. Similar results have been found by others (Malueg et al. 1972; Aubertin et al. 1973; Moore, 1975b; Thut, 1970).

The relatively large number of buffer zone violations suggests that modifications in the urea application procedure are needed to reduce unnecessary nutrient loading to the stream systems.

Urea, NH_3 and NO_3-NO_2 loadings for seven stream sections following fertilization are presented in Figures 8, 9 and 10, respectively. The loadings presented are the difference between the upstream and downstream station and are representive loadings for only that portion of the watershed between the two stations. Because many of the concentrations used in calculating loads were below analytical limits, upper and lower limits of the range which contained the actual loading value were defined and presented in the figures as two separate curves. Therefore when defining the limits, four possible combinations could occur:

Concentrations	Station Loadings		Watershed Loading Range
1) $C_1 \geqq A$, $C_2 \geqq A$	$L_1 = Q_1C_1$	$L_2 = Q_2C_2$	$D = Q_1C_1 - Q_2C_2$
2) $C_1 \leqq A$, $C_2 \geqq A$	$0 \leqq L_1 \leqq Q_1A$	$L_2 = Q_2C_2$	$-Q_2C_2 \leqq D \leqq Q_1A - Q_2C_2$
3) $C_1 \geqq A$, $C_2 \leqq A$	$L_1 = Q_1C_1$	$0 \leqq L_2 \leqq Q_2A$	$Q_1C_1 - Q_2A \leqq D \leqq Q_1C_1$
4) $C_1 \leqq A$, $C_2 \leqq A$	$0 \leqq L_1 \leqq Q_1A$	$0 \leqq L_2 \leqq Q_2A$	$-Q_2A \leqq D \leqq Q_1A$

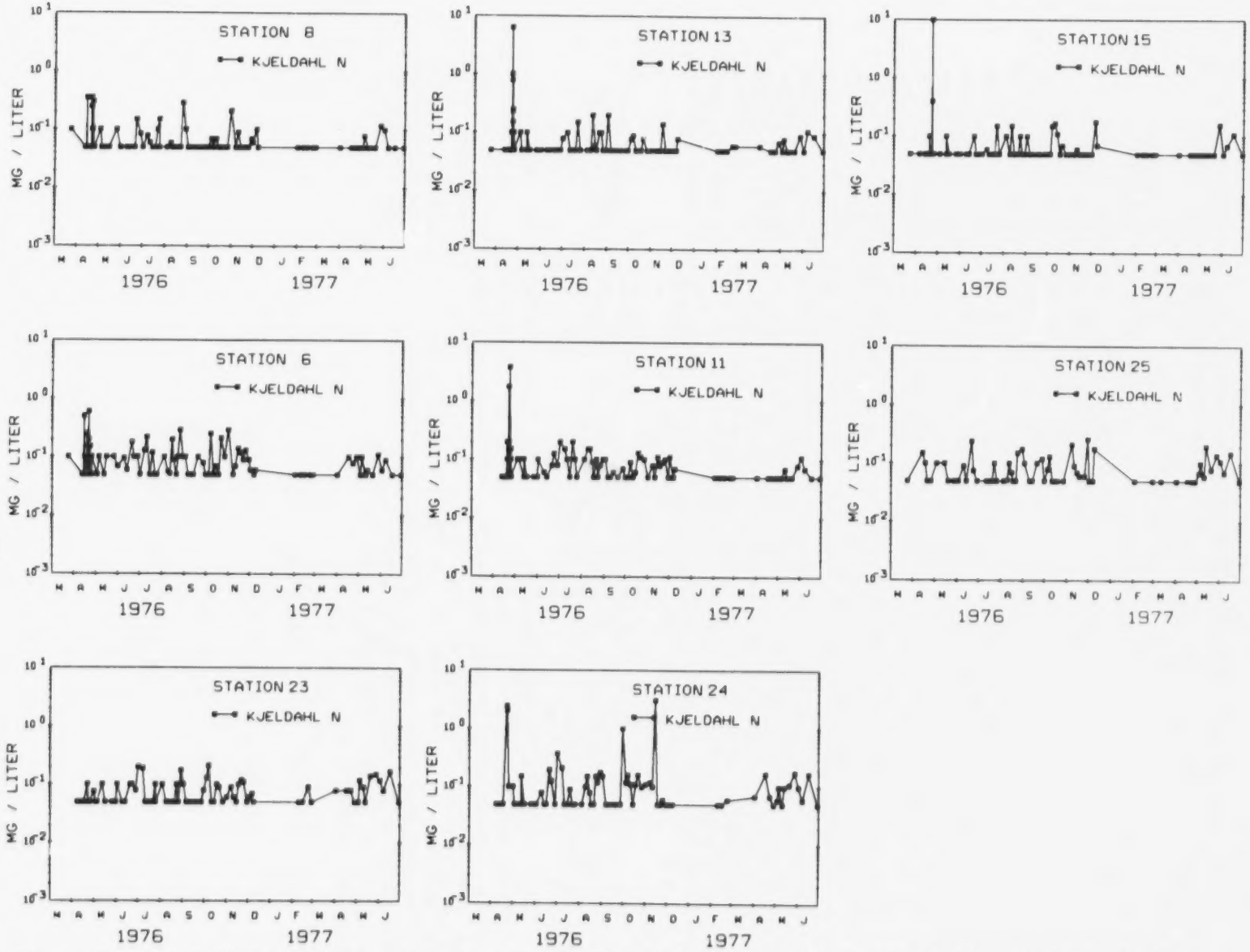

Figure 7. Total Kjeldahl-N concentrations at experimental and control stream stations before, during, and after fertilization of Huckleberry Flats.

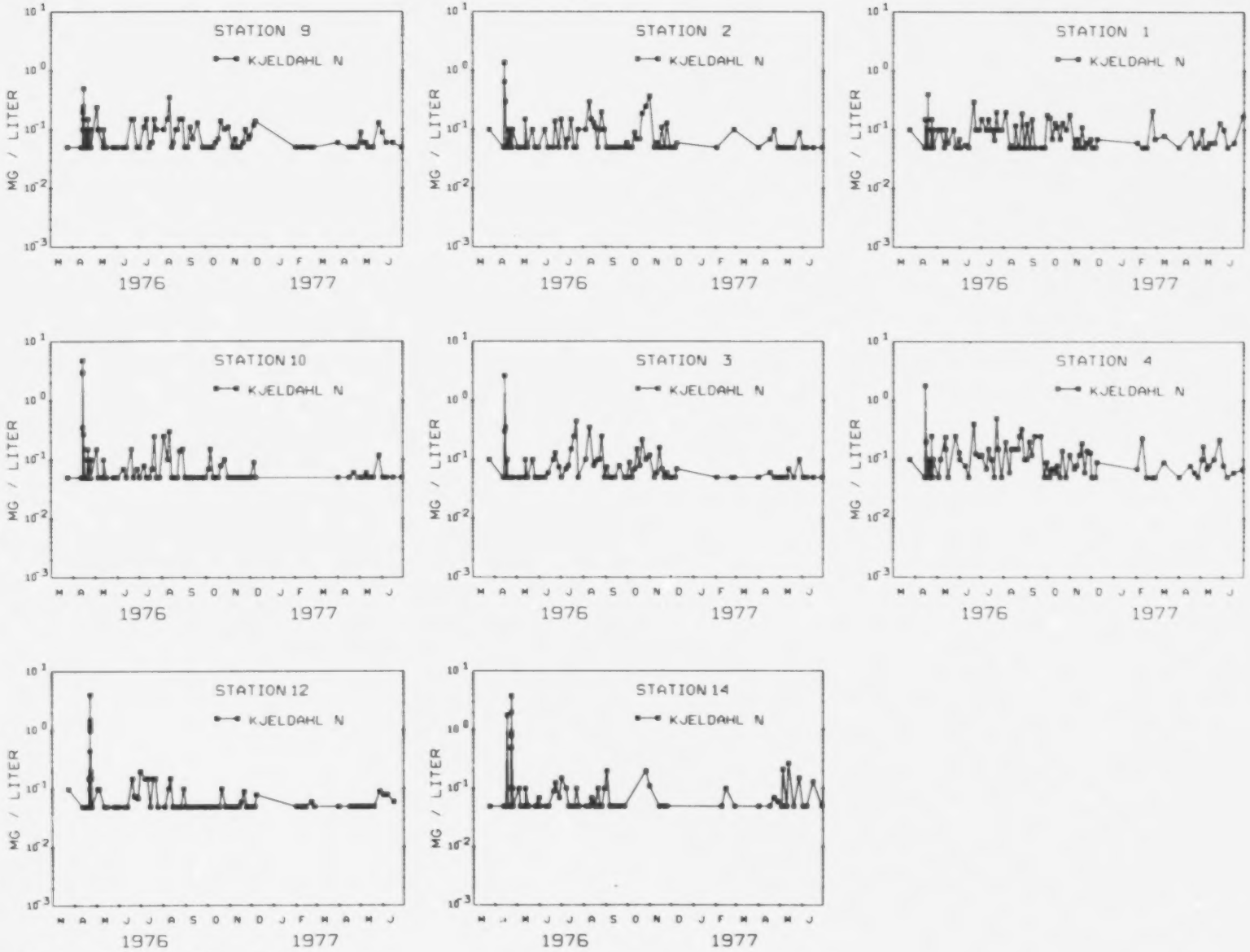

Figure 7. (Continued)

Where:

Q_1 and Q_2 = Flow at the lower and upper stations, respectively
C_1 and C_2 = Concentration at lower and upper stations, respectively
L_1 and L_2 = Loadings (flow times concentrations) at lower and upper stations, respectively
D = Loadings (L_1 - L_2) for watershed between stations
A = Analytical limits; urea = 0.020 mg N/l; NH_3 = 0.005 mg N/l; NO_3-NO_2 = 0.005 mg N/l.

The ranges resulting from these calculations are the most accurate estimate that can be made of the actual loading values.

Urea loadings for all sections ranged about the 0 g N/ha/day loading level (Figure 8) with a wider range at higher flows. No discernible differences between streams buffered by 30 m and 45 m strips were noted. During 1976, urea loadings in Fourth and Salal Creeks were slightly higher than those in Fifth and Sixth Creeks. During 1977, ranges found at all stations overlapped and no differences could be defined.

Ammonia also generally ranged about the 0 g N/ha/day loading level (Figure 9). Again, the wider loading ranges found in Huckleberry Creek sections bracketed ranges found at all other stations and no differences could be defined.

Nitrate-nitrite loading ranges in all stream sections were higher in 1977 than in 1976 except in Fourth Creek (Figure 10). The highest loading values in Fourth Creek occurred during the spring of 1976.

In general, these loading data suggest that urea and ammonia losses were low, generally less than 1 g/ha/day, and on some occasions were negative. Nitrate-nitrite loadings in 1977 were higher and more variable than in 1976 probably representing the residual effects of fertilization. Differences in loading levels between streams buffered by 30 m, 45 m and 0 m strips were too small to be measured. The negative N loading values found for Fourth Creek, which had no buffer zone, were due to a strong negative hydraulic budget rather than decreased nitrogen concentrations.

FISH BIOASSAYS

Fish bioassays using rainbow trout, Salmo gairdneri, were conducted to determine possible fish mortality due to fertilization effects (Perna, 1971). The experiment was originally designed to compare survival in a control stream, Fourth Creek, with survival in experimental streams. Because Fourth Creek was contaminated, no reference can be made to an untreated control. Comparisons between treated stations, however, are possible and informative.

Percent survival of the trout for a 2 month period during and after fertilization is presented in Table 4. Generally, survival was high at all stations. Survival in the smaller streams was very high, 90 to 100%, whereas survival in the largest stream—Huckleberry Creek at Station 8 and 13—was 78 and 82% respectively.

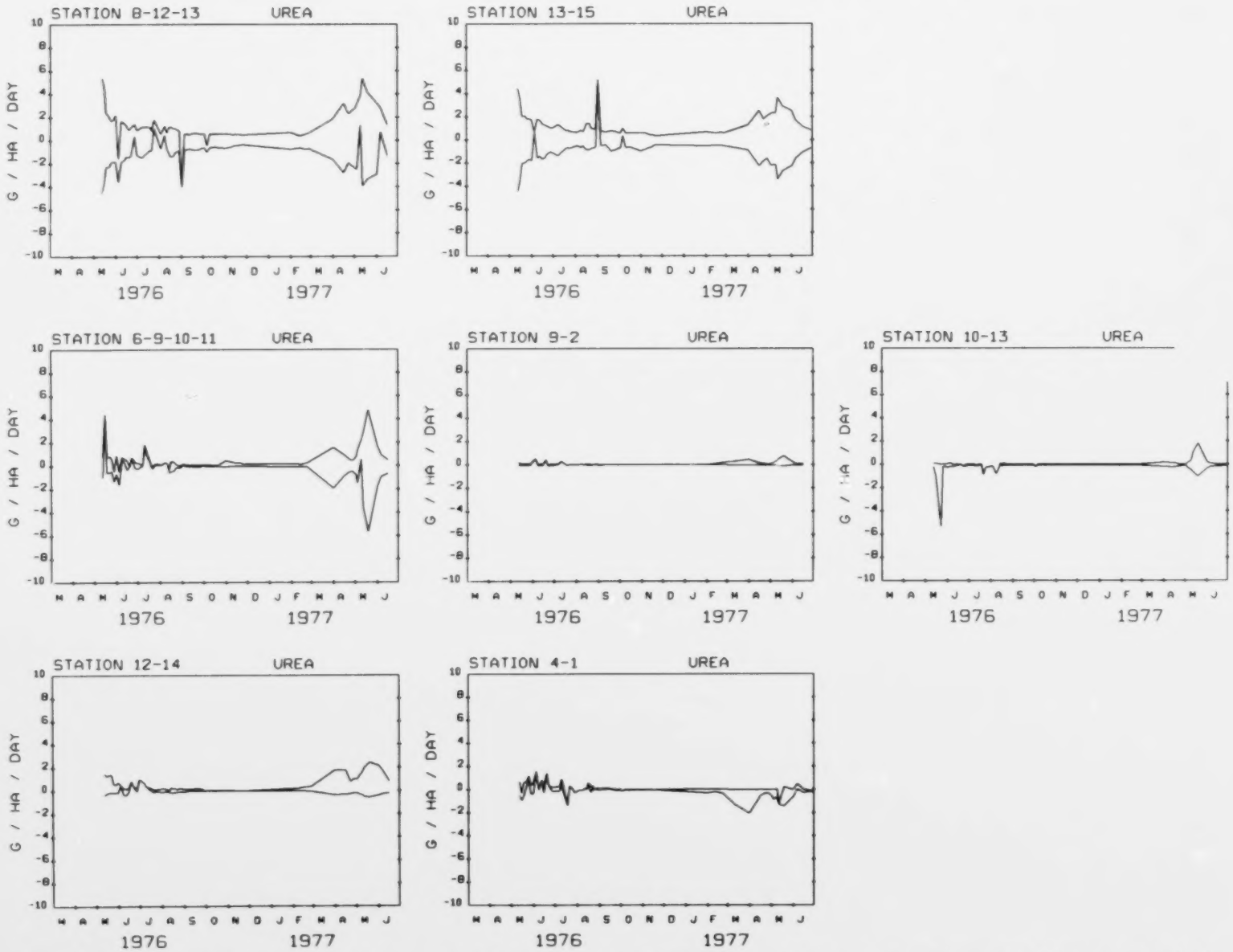

Figure 8. Urea-N loadings following fertilization in Huckleberry, Fifth, Sixth, Seventh, Eighth and Ninth Creeks.

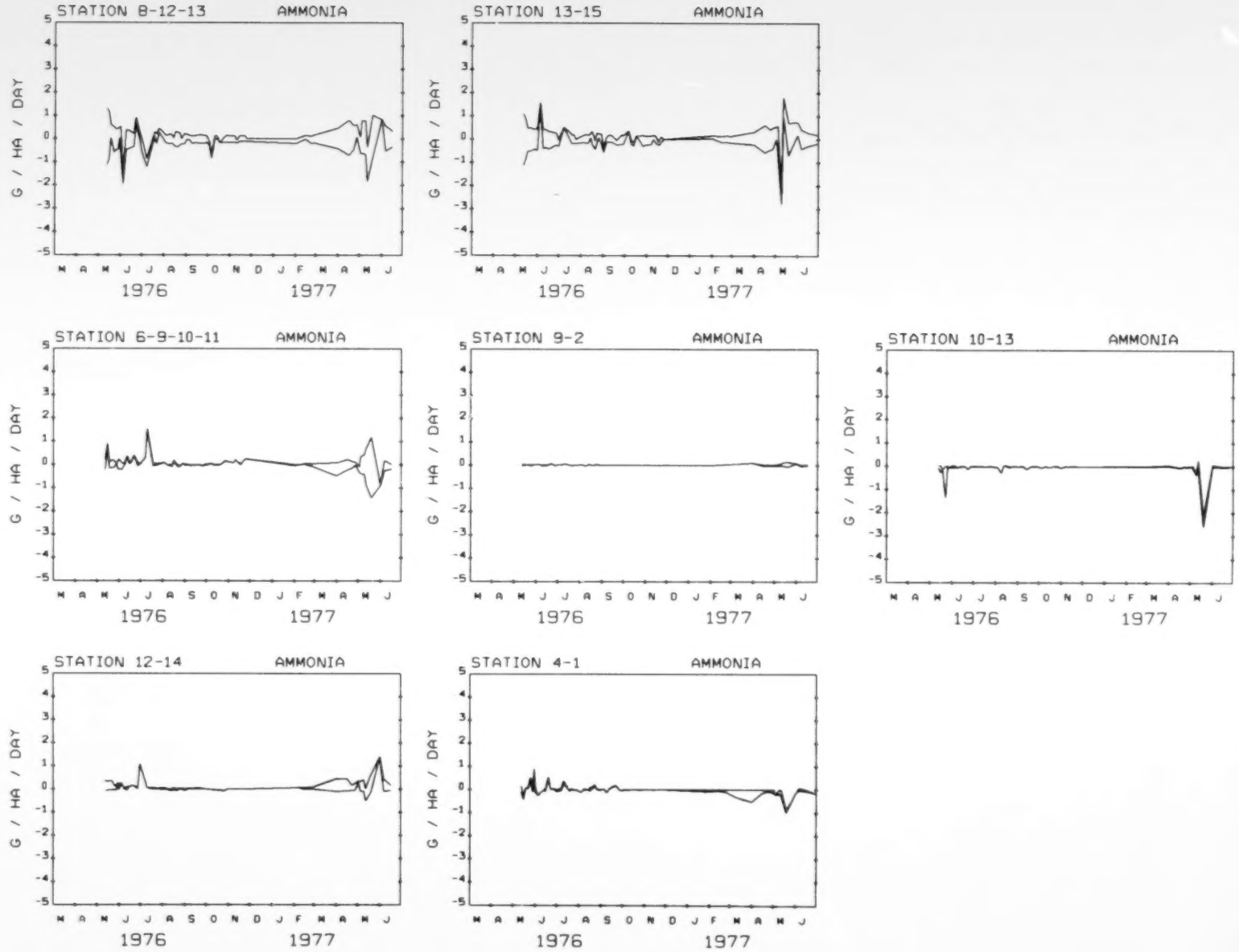

Figure 9. Ammonia-N loadings following fertilization in Huckleberry, Fifth, Sixth, Seventh, Eighth and Ninth Creeks.

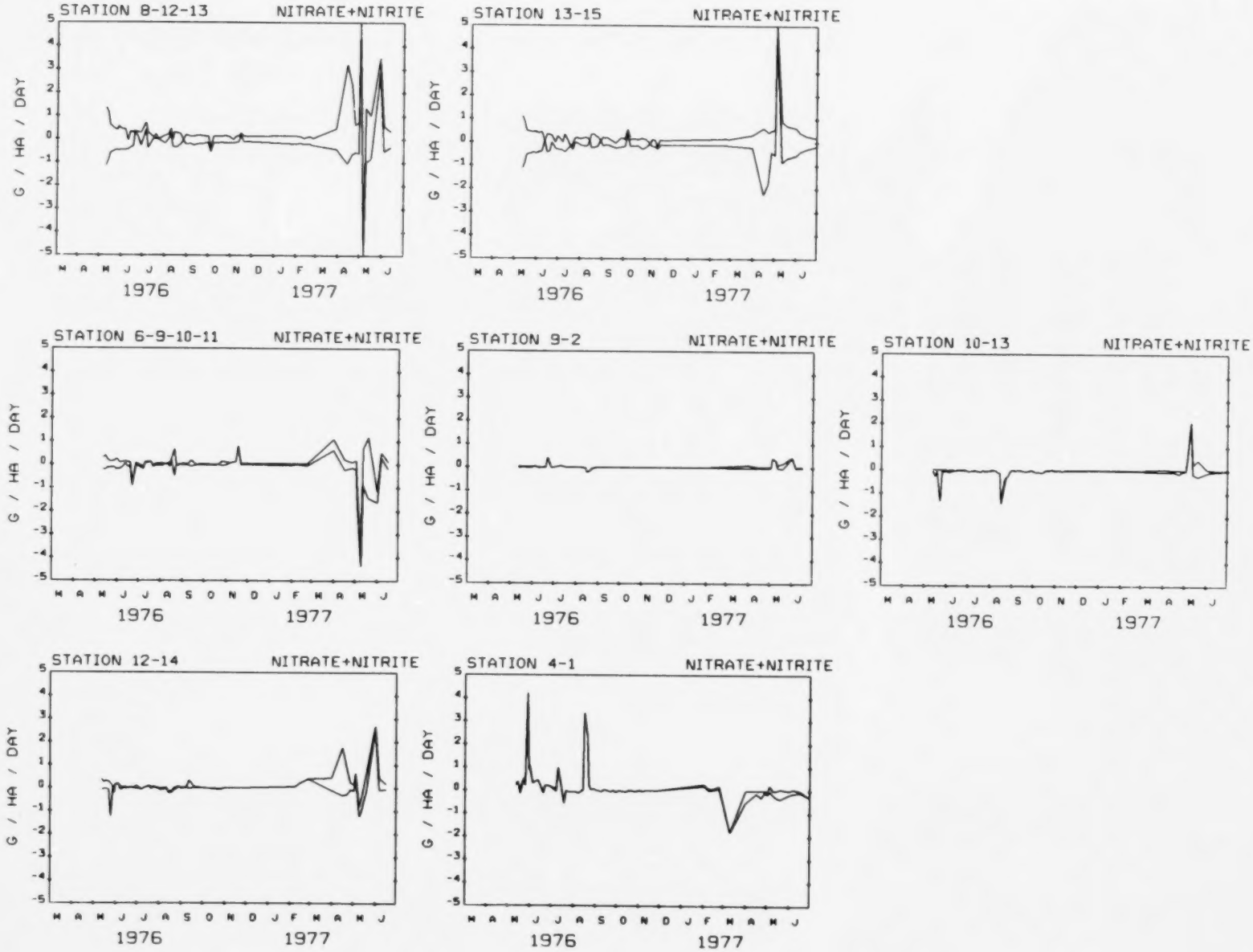

Figure 10. Nitrate-nitrite loadings following fertilization in Huckleberry, Fifth, Sixth, Seventh, Eighth and Ninth Creeks.

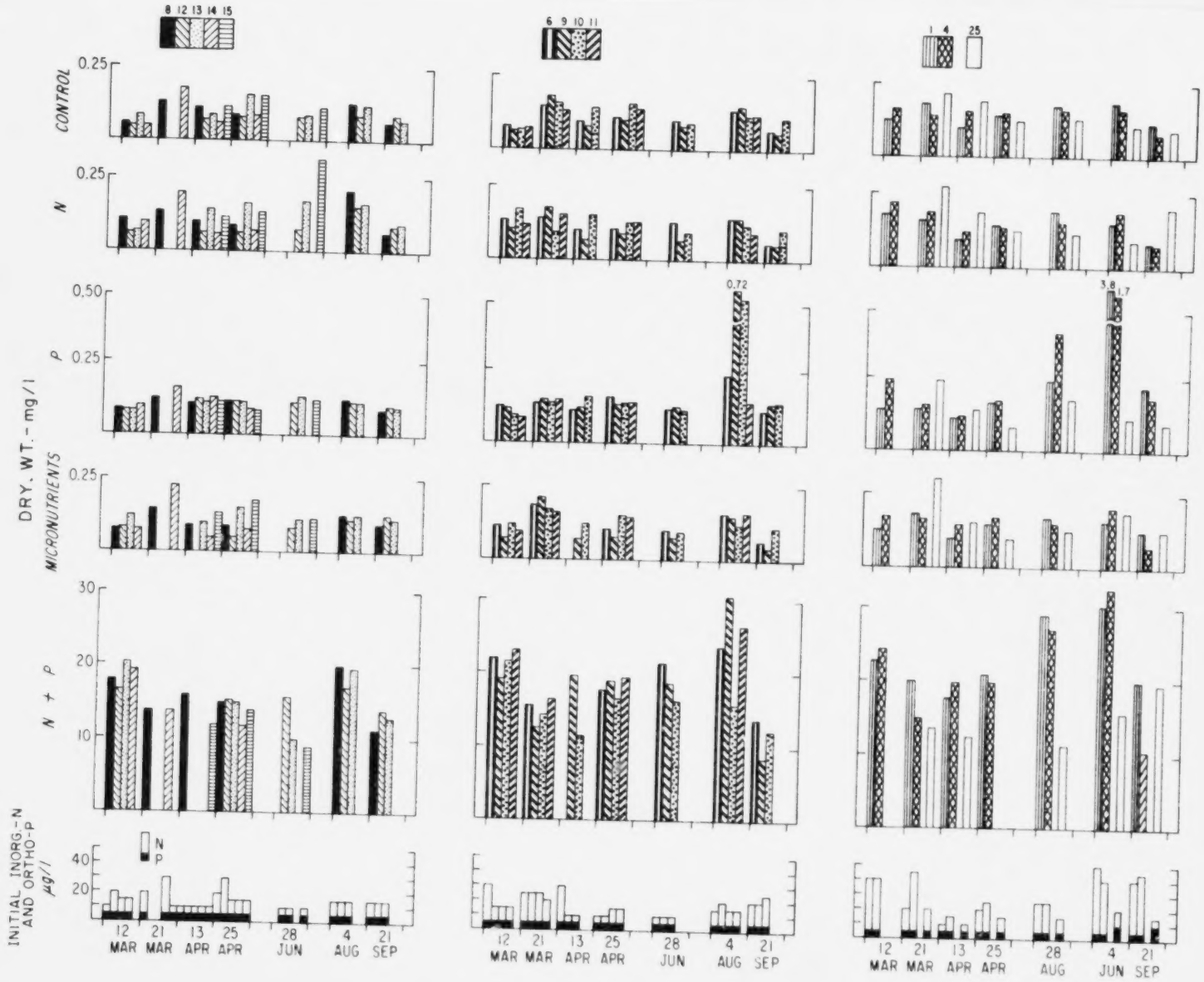

Figure 11. Algal assay growth yields for untreated streamwater; 1.0 mg/l nitrogen addition; 0.05 mg/l phosphorus addition; micronutrient addition; and 1.0 mg/l nitrogen plus 0.05 ml/l phosphorus addition.

TABLE 4. FISH BIOASSAY; PERCENT SURVIVAL OF RAINBOW TROUT, Salmo gairdneri, FOR A 2 MONTH PERIOD DURING AND AFTER FERTILIZATION OF HUCKLEBERRY FLATS

Station	Percent Survival*
1	93
4	93
9	93
10	98
11	100
12	90
14	95
6	95
8	82†
13	78††

* Exposure period was 13 April - 13 June, 1976.

† 12.5 % Mortality before fertilization of upstream watershed.

†† 10.0 % Mortality before fertilization of upstream watershed.

A large portion of mortalities at these two stations occurred prior to fertilization of their upstream watershed. The chemical composition of these two stations was affected the least by fertilization, suggesting that factors other than fertilization were responsible for the higher mortality. One possible explanation is stress caused by higher flow velocities at these two stations.

The results of these studies suggest that percent mortality due to fertilization-related processes was too low to be isolated from nonrelated causes such as high flow velocity. These results are in agreement with the level of mortality that would be expected considering the low ammonia concentrations and near neutral pH values found during the study (USEPA, 1976).

ALGAL GROWTH POTENTIAL

The algal assay results (Figure 11) show the algal growth potential of the stream water using Selenastrum capricornutum under laboratory conditions. These data do not necessarily reflect a response of the indigenous algal populations which may have been mediated by other environmental factors, e.g. light and temperature. They do, however, represent the comparative growth potential of these samples with the test alga.

Assays of samples without nutrient spikes (untreated streamwater) all demonstrated very low growth yields (Miller et al. 1974; Maloney et al. 1972). They showed no increase in yield after fertilization in comparison with the 12 March 1976 sampling prior to fertilization, or with the unfertilized controls, Stations 15 and 25. Only minor variations in yield throughout the sampling

period were observed, and significant differences between stations were not apparent.

The addition of a combined micronutrient spike produced no significant growth increase over that of the controls. This indicated that a micronutrient deficiency did not exist, and would not mask the effect of increased nitrogen by limiting growth.

Streamwater from nitrogen-poor watersheds, such as those in the study area, theoretically would be nitrogen limited. However, the nitrogen additions did not indicate nitrogen limitation prior to fertilization due to the co-limiting effect of low, ambient phosphorus concentrations (Table 3). Orthophosphorus concentrations were generally less than 5 µg/l.

Another indication of an effect of increased nitrogen would be a change in the nutrient limiting growth. The lack of growth response to phosphorus additions suggests that a shift to phosphorus limitation did not occur immediately after fertilization. At Stations 9, 10, 1, and 4, slight phosphorus limitation occurred later in August, but did not persist into September even though inorganic nitrogen and orthophosphorus concentrations were similar to August values (Figure 11). However, the higher urea concentrations occurring at these stations on 4 October (Figure 4) would not be reflected in the inorganic nitrogen values and may have been the nitrogen source causing the slight shift to phosphorus limitation.

Co-limitation is positively indicated by higher yields obtained from samples spiked with both nitrogen and phosphorus. This conclusion is consistant with the generally low concentrations of nitrogen and phosphorus found in the streams during the study period and the general lack of response to singular nitrogen or phosphorus spikes. Although the yields were sufficient to eliminate primary limitation by micronutrients, the variation in yields among the stations suggests that micronutrients may have been secondary limiting factors.

These results strongly indicate that fertilization did not increase the algal growth potential and, in general, did not change the limiting nutrient status of the stream water. A slight shift to phosphorus limitation occurred only on one date in the streams which generally had the higher nitrogen concentrations (Figure 4).

PERIPHYTON GROWTH

Assessment of periphyton growth was used to integrate possible low rate or non-steady-state nutrient loading which may or may not have been apparent in the periodic grab samples for chemical analyses.

Chlorophyll *a* concentrations and biomass as estimated by ATP concentrations in periphyton collected from glass slides which had been exposed for 4 and 8 week periods are presented in Figure 12. In comparison to other studies presently being conducted in the Pacific Northwest, periphyton biomass was low throughout the study period with maximum chlorophyll *a* and biomass values of

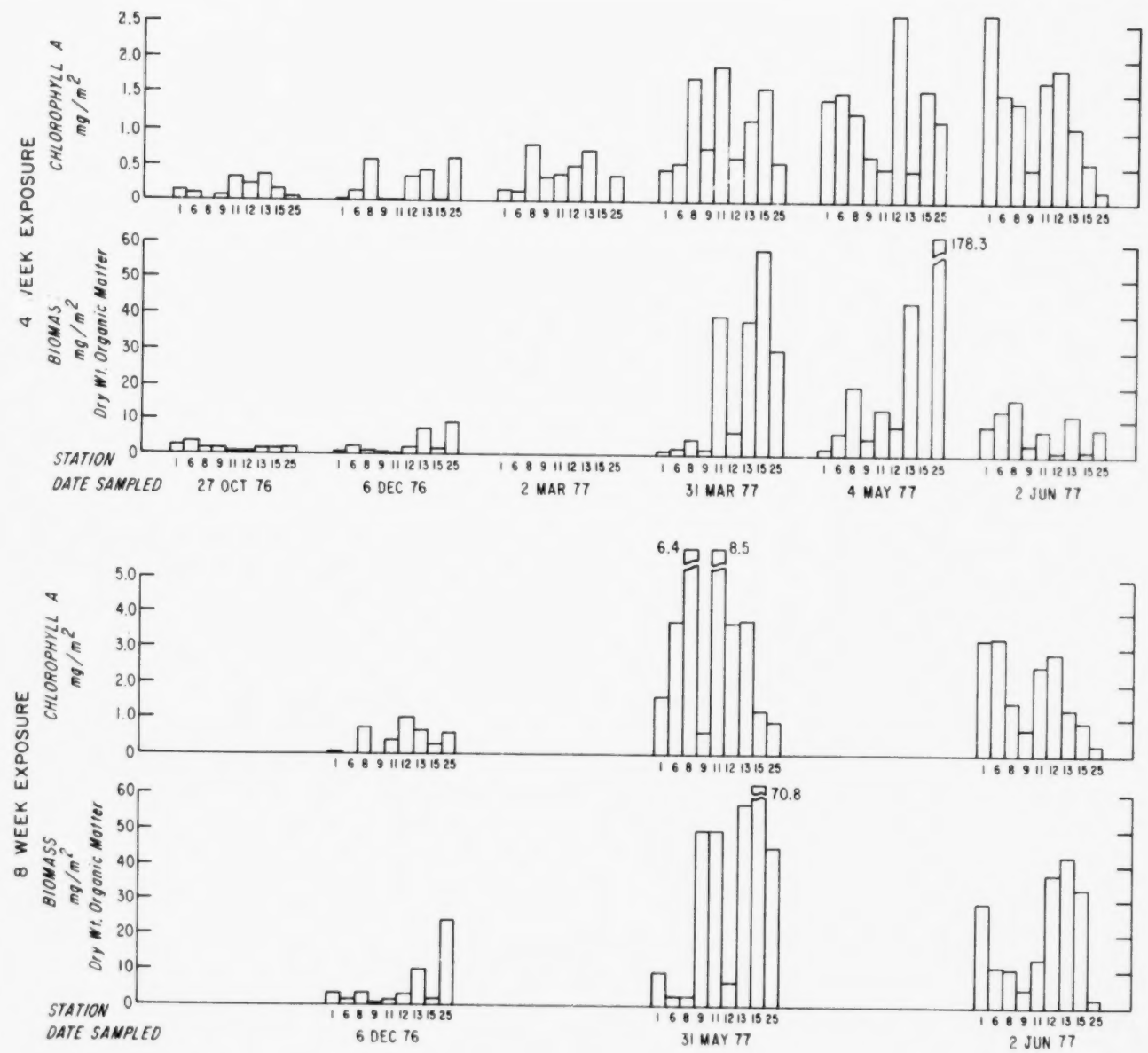

Figure 12. Chlorophyll a and viable biomass concentrations of periphyton on glass slides exposed in control and experimental streams for 4 and 8 week periods.

2.5 and 178 mg/m^2, respectively, for the 4 week exposure period and 8.5 and 70.8 mg/m^2, respectively, for the 8 week exposure period.

From 27 October 1976 to 2 March 1977, growth at all stations was very low. After this period growth began to increase, and most stations reached a maximum sometime during March to May. During May to June, growth was probably slowed by the reduction in light resulting from leaf-out and development of the riparian canopy.

These changes through time are also shown by the mean chlorophyll a and biomass concentrations of all stations for each 4 and 8 week exposure period presented in Table 5A. The variation among stations can also be seen by comparing means of all samples collected during the study period for each station (Table 5B).

TABLE 5. PERIPHYTON; MEAN CHLOROPHYLL A AND MEAN BIOMASS CONCENTRATIONS AT ALL STATIONS FOR EACH SAMPLE COLLECTION DATE AND FOR ALL SAMPLE COLLECTION DATES AT EACH STATION FOLLOWING FERTILIZATION OF HUCKLEBERRY FLATS

A. Means of all stations for each sampling date.

	4 week exposure		8 week exposure	
Date	Chlorophyll a (mg/m^2)	Biomass (mg/m^2)	Chlorophyll a (mg/m^2)	Biomass (mg/m^2)
27 Oct 1976	0.14	4.1		
6 Dec 1976	0.20	6.8	0.38	12.5
2 Mar 1977	0.38	-		
31 Mar 1977	1.03	48.4	3.40	76.3
4 May 1977	1.33	60.2		
2 Jun 1977	1.20	24.2	1.82	48.2

B. Means of all dates for each station

	4 week exposure		8 week exposure	
Station	Chlorophyll a (mg/m^2)	Biomass (mg/m^2)	Chlorophyll a (mg/m^2)	Biomass (mg/m^2)
1	0.81	6.5	1.62	32.3
6	0.66	10.5	2.36	11.5
8	0.96	26.0	2.90	12.1
9	0.34	4.4	0.34	41.0
11	0.62	24.6	3.83	50.8
12	1.03	7.7	2.55	36.3
13	0.77	41.0	1.90	86.5
15	0.65	40.0	0.82	84.5
25	0.43	55.1	0.51	56.0

To determine if a significant difference (0.05) occurred between fertilized and non-fertilized stations, the sum of squares was partitioned (Snedecor and Cochran, 1967) and F-test evaluated for experimental Stations 6, 8, 11, and 13 and control Stations 15 and 25. These experimental stations were selected on the basis of their physical similarity to the control streams. Differences between the control and fertilized stations were significant for chlorophyll *a* for the 8 week exposure period. Differences in chlorophyll *a* for the 4 week period were not significant. When comparing the mean chlorophyll *a* values for the 8 week exposure, fertilized stations consistently had higher chlorophyll *a* values than controls. The only exception was Station 9 which was located in an area heavily shaded with a dense coniferous canopy. Biomass, which includes both autotrophs and heterotrophs, was not significantly different in control and experimental streams for either the 4 or 8 week exposure periods.

These data suggest that although there was a slight shift to a more autotrophic biomass, as shown by chlorophyll *a*, the overall biomass was not changed by fertilization.

DECOMPOSITION

The results of the decomposition experiments conducted at Stations 6 and 25 are summarized in Table 6. With the exception of Station 6, 1 April-2 June 1977 decomposition and processing coefficients for Douglas fir were very similar for the two test periods at both the control (25) and experimental (6) stations. Decomposition and processing coefficients for Station 6, 1 April, were about one-half of those for all other Douglas fir experiments and total weight loss was less than estimated leaching losses. Biomass for these samples, however, was similar to the otner samples which indicates these low values cannot be attributed to a high decomposer biomass. A second analysis was conducted on all samples collected on that date after having been frozen for several months. These results showed Station 6 to be similar to Station 25 and weight losses for all samples collected on that date were 15 to 20% higher after cold storage. These data suggest that the values presented for Station 6, 1 April-2 June, are low, and the true values were probably similar to those of Station 25. However, because the samples may have changed, the data can only be used for relative comparisons among stations.

Decomposition and processing coefficients for red alder were generally higher than those for Douglas fir, probably due to the higher food quality of red alder substrate (Petersen and Cummins, 1974; Triska *et al.* 1975). Decomposition of red alder was marginally but consistently higher at the control (25) than at the experimental (6) station.

Processing coefficients for Douglas fir (0.0055 to 0.0064) and red alder (0.0072 to 0.0089) measured in these experiments were similar to those found for leaf packs (0.0049 to 0.0057 and 0.0077 to 0.0099, respectively) in three replicate experimental Cascade streams by Triska and Sedell (1976). These streams uniquely lacked an invertebrate leaf-shredder population and thus closely represented microbial decomposition processes as did the dialysis chamber. The investigators also found no discernible difference in leaf pack

TABLE 6. HETEROTROPHIC DECOMPOSITION; PERCENT DECOMPOSITION AND PROCESSING COEFFICIENTS OF DOUGLAS FIR, P. menziesii, AND RED ALDER, A. rubra, SUBSTRATES IN DEVILS CANYON CREEK AND SEVENTH CREEK

Location	Incubation Period	Processing† Coefficient (k)		Decomposition‡ (%)		Biomass (mg/g residue)	
Douglas fir Substrate							
Seventh Cr.	22 Aug-7 Dec 1976	.0058	.0062	4	9	.103	.086
Devils Canyon Cr.	22 Aug-7 Dec 1976	.0058	.0062	4	6	.037	.021
Seventh Cr.	1 April-2 June 1977	.0034	.0034	-10	-10	.057	.178
Devils Canyon Cr.	1 April-2 June 1977	.0055	.0064	4	0	.066	.106
Alder Substrate							
Seventh Cr.	22 Aug-7 Dec 1976	.0072	----	14	--	.139	---
Devils Canyon Cr.	22 Aug-7 Dec 1976	.0074	.0089	15	21	.273	.089
Seventh Cr.	1 April-2 June 1977	.0074	.0074	12	12	.033	.006
Devils Canyon Cr.	1 April-2 June 1977	.0082	.0082	15	15	.143	---

† Conformance of decomposition to an experimental model was assumed and K was calculated from $\text{Log}_e \left(\frac{Wt}{Wo}\right) t = -k$

‡ Decomposition equals total weight lost minus an estimated leaching loss of 29% for Douglas fir, and 25% for Red Alder.

decomposition in these three replicate streams which differed only in mean NO_3 concentrations (0.037, 0.059, and 0.138 mg N/l).

In our study, the maximum range of available nitrogen (NO_3-NO_2 and NH_3) among all stations was 0.010-0.038, and for Stations 6 and 25 was 0.010-0.019 mg N/l. These values suggest that no discernible difference in decomposition would be expected among both control and experimental stations. The lack of significant differences in processing coefficients at Stations 6 and 25 confirmed this assumption. Biomass values, as estimated from the ATP concentration at the end of each experiment, were all low, ranging between 0.006 and

0.273 mg dry weight biomass/g residue. Although comparable biomass data were not available in the literature, a range of reported ATP values was converted to biomass units for comparison. The range of substrates and viable biomass included marine sediments at 130 mg/g (Ernst, 1970), decomposing marine angiosperm disks at 22.8 mg/g (Knauer and Ayers, 1977), and mixed liquor volatile solids from an activated sludge unit at 330 mg/g (Patterson et al. 1970).

The decomposing marine angiosperm, although quite different, is probably the most similar of the three to the substrates used in these experiments and is approximately a factor of 80 greater than our highest value. An explanation for these low biomass values may be that both red alder and Douglas fir substrates were initially nutrient limited and after leaching became even more so (Triska et al. 1975). This condition forces the decomposers to remove nutrients, such as nitrogen and phosphorus, from the water phase in order to continue using leaf substrate as a carbon source (Triska and Sedell, 1976; Triska et al. 1975; Hynes and Kaushik, 1969). The low decomposer biomass found in these chambers is in agreement with the nutrient-poor condition found in the water phase of these streams (Table 3) and the low supporting capacity of these waters for periphyton and S. capricornutum in the algal assay.

The results of these decomposition experiments suggest that both the control and experimental streams supported a low heterotrophic biomass and exhibited low processing coefficients as a result of their oligotrophic condition. These data also suggest that fertilization did not cause a detectable change in the decomposer biomass or processing rate.

STREAM BENTHIC COMMUNITIES AND INVERTEBRATE DRIFT

The numbers of benthic invertebrates found at sampling stations and the Shannon-Wiener diversity index (SWDI) are presented in Figure 13. The predominant organisms collected in the Surber samples from all stations throughout the study belonged to the orders Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies). Dipterans (true flies) were abundant during the spring at Stations 6, 8, 10, and 11; however, their numbers decreased during the summer. Coleoptera (beetles), Zygoptera (damselflies), Megoloptera (alderflies and dobsonflies), and Oligochaeta (segmented worms) were represented by only a few individuals. A variety of ephemeropterans and Plecopterans were present before and after fertilization. Cinygmula sp, Paraleptophlebia sp, Ironodes nitidus, and Baetis bicaudatus were the most commonly encountered ephemeropterans and exemplify the variety of the mayfly community. The plecopterans were not as numerous nor as well represented in number of taxa as the mayflies. The more notable were Alloperla sp, Peltoperla sp, and Nemoura sp, which occurred both before and after fertilization. Trichopterans were also collected before and after fertilization and were fewer in both numbers and kinds than the plecopterans. The pattern of occurrence of the trichopterans was similar to that of the ephemeropterans and plecopterans with Wormaldia sp, Micrasema sp, and Rhyacophila sp occurring most often. There appeared to be no consistent pattern or difference in species composition of the benthic communities sampled that could be attributed to forest fertilization.

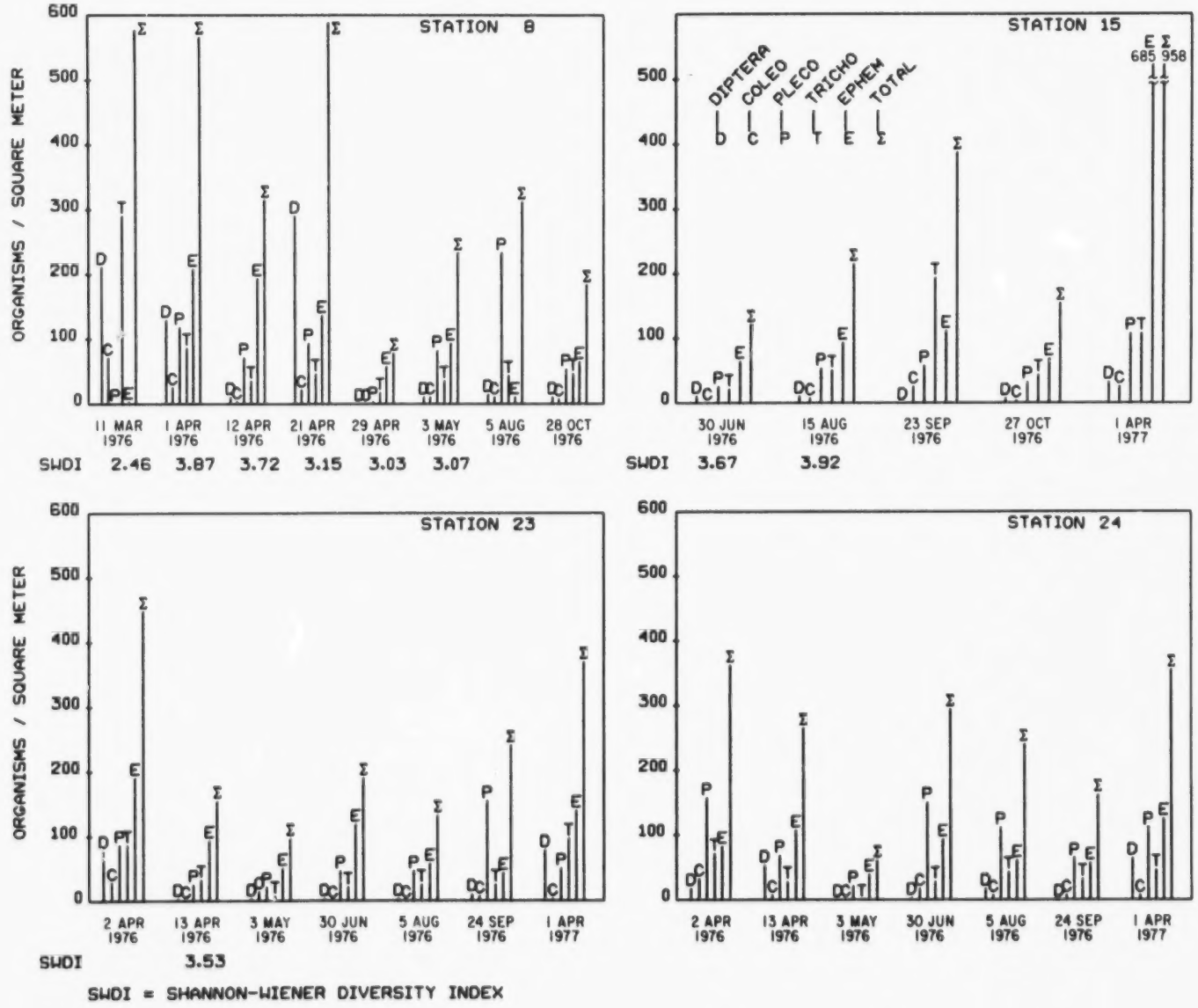

Figure 13. Numbers of benthic organisms in predominant orders at control and experimental stations.

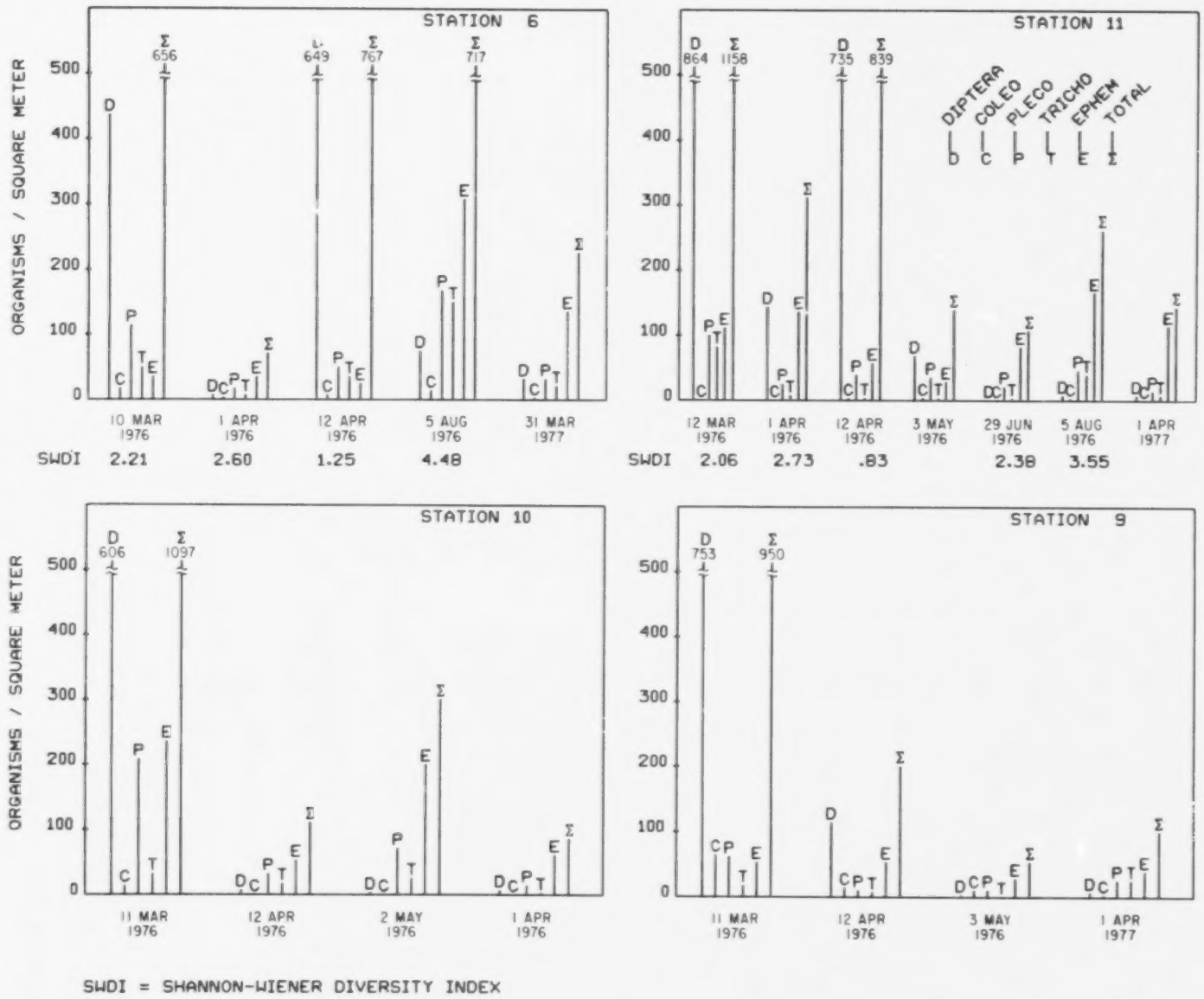

Figure 13. (Continued)

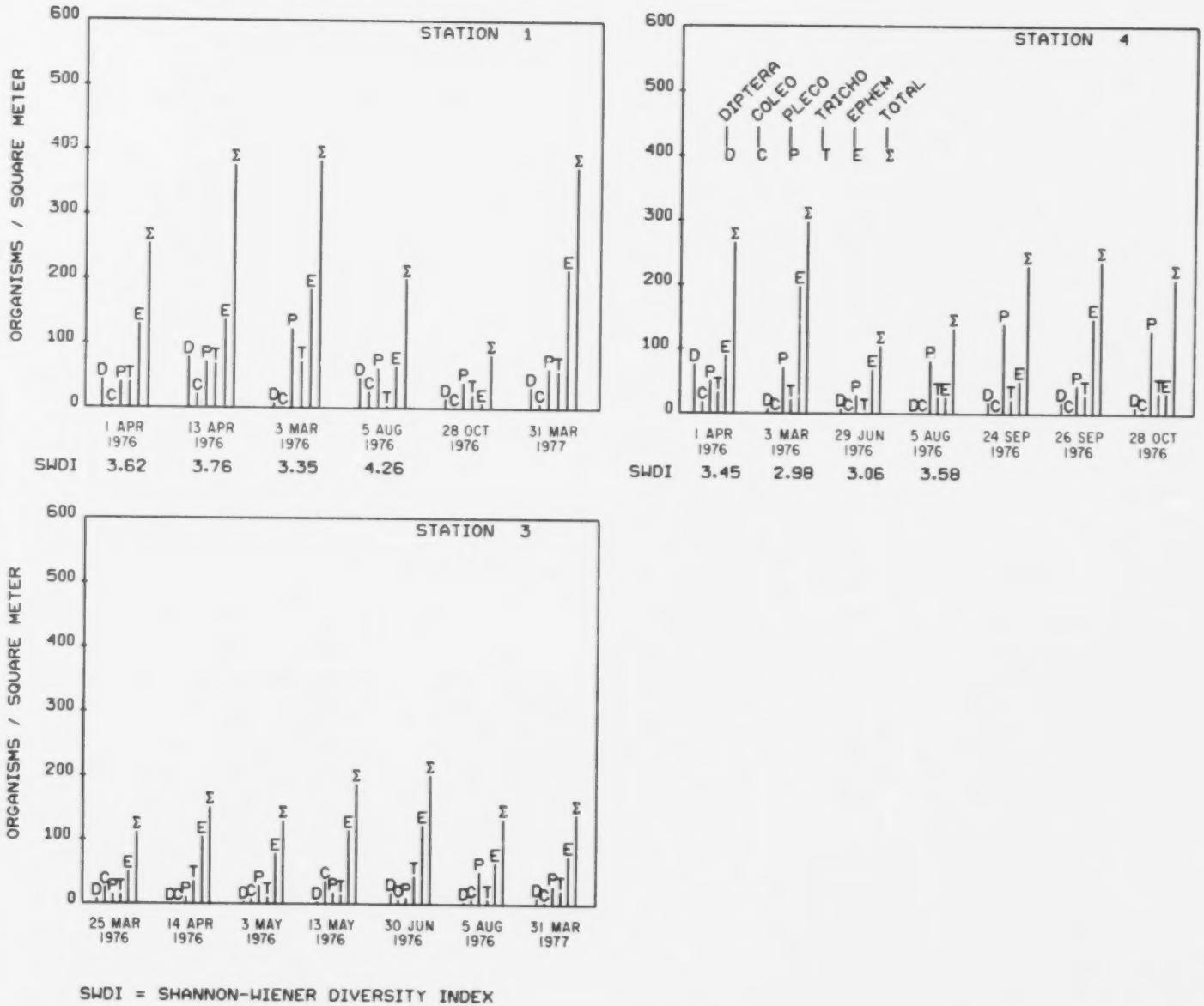

Figure 13. (continued)

The Shannon-Wiener diversity index (SWDI) was calculated only for samples identified to the lowest taxon possible, usually genus. The lowest indices 1.25 and 0.83 occurred on 12 April 1976 before fertilization at Stations 6 and 11 respectively. These low values were due to the extreme dominance of the blackfly, Prosimulium sp, rather than a reduction in the number of species present. Generally, the diversity index values for all stations before and after fertilization ranged between 0.83 and 4.48 with no trend which would suggest that fertilization affected community diversity.

In an attempt to discriminate between natural, temporal, and spatial variation in the benthic community and those variations related to fertilization, a clustering method (Swartz, 1978; Boesch, 1977; Walker, 1974) was applied to a Bray-Curtis dissimilarity matrix developed for all stations and dates. The results are presented as a dendrogram in Figure 14.

If fertilization had a measurable effect on the benthic community it would be expected that samples collected before fertilization and from control stations would form different clusters than stations affected by fertilization, and clusters resulting from differences in natural stream habitats would appear separately for non-fertilized and fertilized stations.

The dendrogram shows no separation of fertilized and unfertilized samples. Cluster I contains predominantly samples from streams with higher flows and from stations at higher elevations with steeper slopes. The flows for most of these stations at the time of collection were around 10^2 l/sec. Within this main cluster there are three sub-clusters with higher intrafaunal homogeneity. The sub-cluster farthest to the left contains samples collected from the larger streams during the low flow summer-fall period and from smaller streams during the spring when flows were relatively high. The other two sub-clusters predominantly contained samples collected during the spring from larger streams.

Samples clustered in Group II were mostly collected during summer-fall from stations with flows of 10^2 l/sec or less. Group III contains samples collected from mostly medium to small streams during the spring when flows were relatively high, about 10^2 l/sec. Samples clustered in IV were all collected during early spring when flows were the highest, generally in the 10^2 to 10^3 l/sec range, from stations located in the Flats area.

In general, flow and season appeared to be the factors most common to the samples contained within the major clusters. The presence or absence of a fertilized upstream watershed was not a common factor for any cluster. Although Group IV had only one post-fertilization sample, the samples contained within this cluster were all collected during early spring when flows were the highest. All other groups contained samples from both control and fertilized stations or from "before" and "after" fertilization periods suggesting that fertilization had no effect separable from natural causes.

Drifting invertebrates were collected from Salal, Huckleberry, Fifth, Sixth, Seventh, and Fourth Creeks. As previously mentioned, Fourth Creek was originally intended as a control stream but was heavily contaminated during fertilization. The predominant drift organisms collected in Fourth Creek were

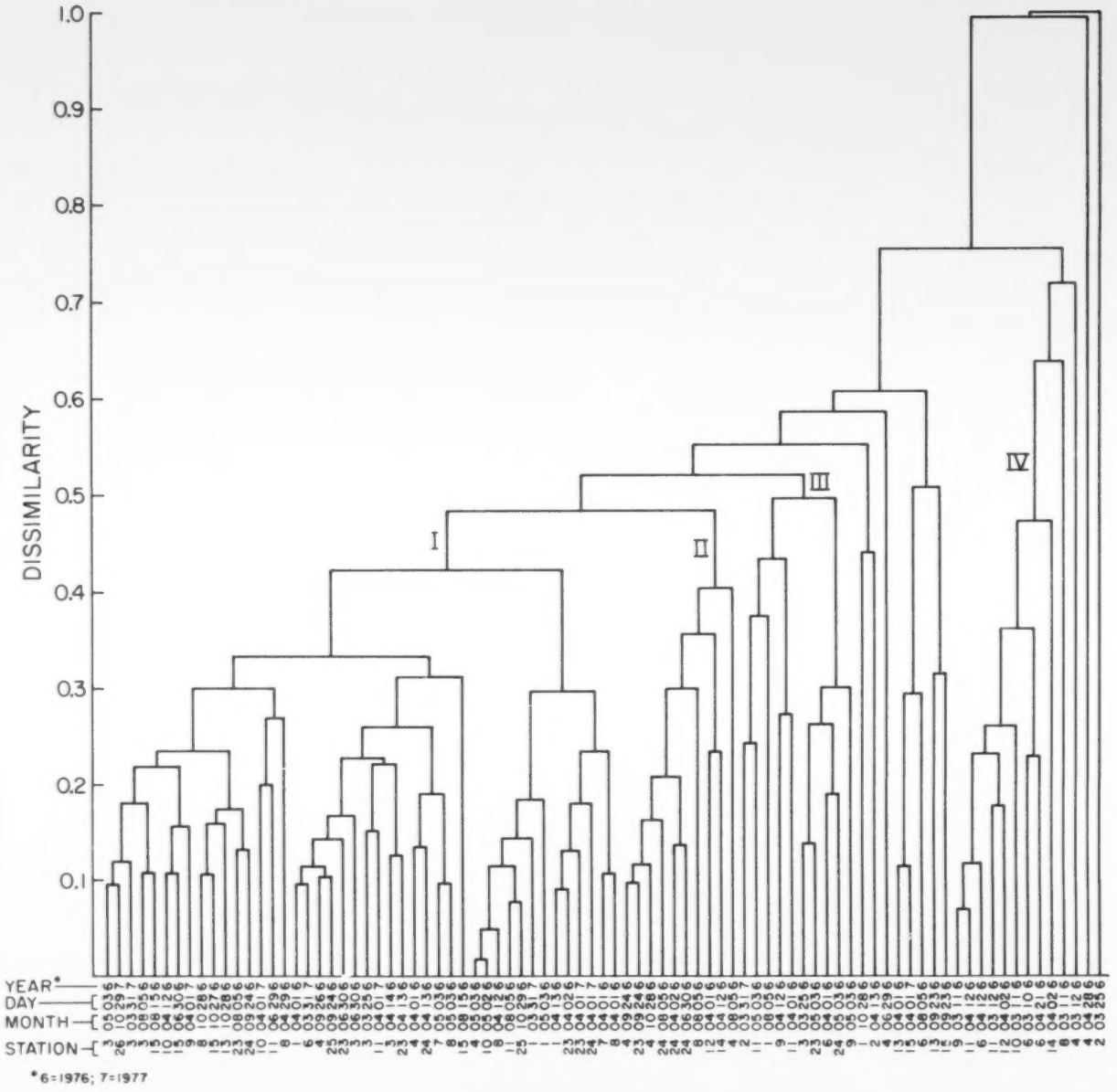

Figure 14. Dendrogram developed from cluster analysis of a Bray-Curtis dissimilarity matrix of benthic invertebrates collected from control and experimental stations before and after fertilization of Huckleberry Flats.

Baetis bicaudatus and Prosimulium sp. Other organisms of significance in the drift included the ephemeropterans Paraleptophlebia sp, Ameletus sp, and Ironodes sp; and the plecopteran Nemoura sp.

Organisms collected from Fifth and Sixth Creeks were identified only to order; however, dipterans and ephemeropterans were also predominant in these drift samples.

Seventh Creek was also predominated by Prosimulium sp and B. bicaudatus. The plecopteran Peltoperla sp was prominant during early spring. Other organisms captured in significant numbers from Seventh Creek were the ephemeropterans Paraleptophlebia sp and Ameletus sp; the plecopterans Nemoura sp, Isoperla sp and Pteronarcella sp; and the trichopterans Wormaldia sp and Rhyacophila sp.

Drift in lower Huckleberry Creek was dominated by Prosimuium sp, B. bicaudatus and Ironodes nitidus whereas upper Huckleberry Creek was dominated by B. bicaudatus. Other organisms which were numerous on occasion in upper Huckleberry Creek were I. nitidus, Prosimulium sp, Nemoura sp, Peltoperla sp, Rhyacophila sp, and Micrasema sp.

Drift in Salal Creek differed from the other streams in that the plecopteran Nemoura sp rather than B. bicaudatus shared dominance with the blackfly, Prosimulium sp. Because of the frequent occurrence and high numbers of Nemoura sp in Salal Creek, this organism appeared to be characteristic of this stream.

In general, the predominant organisms drifting in all streams except Salal Creek were the dipteran Prosimulium sp, and the ephemeropteran B. bicaudatus.

Total numbers of drifting organisms, number of taxa, and Shannon-Weiner diversity index (SWDI) are presented in Table 7. Drift samples collected from Stations 9 and 10 were analyzed to order only and therefore a diversity was not calculated. Highest drift occurred in early spring during the pre-fertilization and fertilization phases when flows were high. Following this period, drift decreased as did flow (Figure 3). Peak drift rates which occurred during the study were usually due to high numbers of Prosimulium sp and B. bicaudatus.

Index values for drift in the larger streams, Seventh and Huckleberry Creeks, were higher than those in the smaller streams, Fourth and Salal Creeks. The lower values in these two smaller streams were due to large numbers of a few species drifting and low evenness (Table 7), rather than a reduction in diversity of taxa present.

These data suggest that community structure with respect to diversity, richness, and types of organisms present was independent of fertilization dates and resultant nitrogen concentrations. Variations which did occur appeared more dependent on season, flow, and possibly emergence period of Prosimulium sp and B. bicaudatus.

TABLE 7. TOTAL NUMBER OF ORGANISMS, NUMBER OF TAXA, AND SHANNON-WIENER DIVERSITY INDEX (SWDI) FOR INVERTEBRATE DRIFT BEFORE, DURING, AND AFTER FERTILIZATION OF HUCKLEBERRY FLATS

	Station 6			Station 11			Station 8			Station 13			Station 9	Station 10			Station 12		
Date	Total	Taxa	SWDI	Total	Taxa	SWDI	Total	Taxa	SWDI	Total	Taxa	SWDI	Total	Total	Taxa	SWDI	Total	Taxa	SWDI
26 March	350	38	3.46	1192	28	2.43	103	27	3.82					73					
13 April	255	25	3.11	100			567	40	3.04	208	33	3.51	1438	77	16	3.18	2972	20	1.54
14 April	605	43	3.75				271	30	3.12	410	35	2.79	1286	146					
15 April	388	45	3.96				180	27	3.36	129	26	3.94	919	90	20	3.60	1793	24	1.83
16 April	360	35	3.55							216	23	2.65	379	88			4042	26	1.40
17 April	150	26	3.59	419	29	3.77	167	24	3.25	272	30	3.08	653				2051		
18 April				296	32	4.12	286	31	3.58	348	29	2.69	594	44			4682	16	1.24
19 April	99	25	3.47	118	25	4.12	329	32	3.39	403	29	2.52	250						
20 April	148	26	3.77	633	39	3.62	213	25	3.50	180	26	2.85	239				1708	27	2.07
21 April	207	30	3.76	260	28	4.04	194	32	4.02	342	37	3.43	246	15			1891	24	1.89
22 April	86	28	4.36	117	26	4.11								18			1049	24	2.13
23 April	124	30	4.37	147	13	3.14	190	28	3.80				390	15			1069	23	2.51
24 April	162			262	37	4.37	102	28	4.27				123	22			753	32	2.92
03 May	30	13	3.21														763	13	0.65
14 May	160	26	3.60	92	14	3.05	205	20	3.55	192	38	3.95	425	366			1696	20	1.01
01 June	128	31	4.42	50	8	2.13	305	37	4.52				62	94			140	9	2.01
29 June	193	40	4.43	67	21	3.72	243	36	4.48					41			79	17	3.29
05 August							228	34	4.49				20				13	7	2.50
23 September	34						43			17			5						
28 October	39									34			42						

(continued)

TABLE 7 (cont.)

Date	Station 14			Station 1			Station 4		
	Total	Taxa	SWDI	Total	Taxa	SWDI	Total	Taxa	SWDI
26 March				400	40	4.28			
13 April	1716						74	12	3.05
14 April	2782	14	1.18	658	28	1.59	587		
15 April	629	17	1.23	530			191		
16 April				458	27	1.61	311	27	3.55
17 April	948	10	0.99	595	28	3.18	151	22	3.64
18 April	1778	10	0.69	441	28	1.78			
19 April	980	12	1.10	42	13	2.77	84	25	3.99
20 April	2988	13	0.76	121	27	3.91	66	25	4.11
21 April	1108	4	0.72	905	36	2.07	95	24	3.86
22 April	2232	33	1.31				189	28	3.89
23 April	1078	15	1.21	286	24	2.15	220		
24 April				515	32	1.88			
03 May	32	10	2.55						
14 May	533	13	1.20				69	18	3.07
01 June	26	7	2.38	54	21	3.60	375	30	3.17
29 June				111	26	3.48	90	22	3.80
05 August									
23 September				12					
28 October				71			29		

Cluster analysis was conducted on these data. Because the data base was greater than the capacity of the computer program (Kaniston, 1978), two matricies were developed. One included data from the "before" and "during" fertilization periods (Figure 15), and the other included "before" and "after" as well as every third day during the fertilization period (Figure 16). The dendrogram for the fertilization period (Figure 16) appears to have about five main collection clusters with a high degree of dissimilarity and which contain subgroups of high intra-group faunal homogeneity.

Lower Huckleberry, lower Seventh and lower Fourth Creeks generally exhibited a higher faunal homogeneity. Upper Fourth Creek appears to be similar to upper Huckleberry Creek, and Fifth Creek collection dates are separated into two distinct periods, an early fertilization and a late fertilization period. Salal Creek, as mentioned earlier, was unique and predominated Group V which was also most dissimilar to all other groups.

Within these subgroups of high faunal homogenity are stations with fertilized and unfertilized watersheds, or pre-fertilization and post-fertilization dates for the same stations, or both.

In general the data suggest that drift populations in the Flats area are dissimilar to those found on the steeper slopes, and that Salal Creek was somewhat unique. This analysis procedure, however, does not demonstrate any grouping of fertilized or nonfertilized dates, suggesting that application of the fertilizer had no measurable effects.

The dendrogram for the combined fertilization and post-fertilization periods is presented in Figure 16. There are five main clusters which are very dissimilar. The subgroups formed within these main clusters generally separate larger streams from smaller streams for spring, summer, and fall. Due to the contamination of Fourth Creek (a control) few comparisons can be made to stations with no unfertilized upstream watersheds. The main comparison which can be made is among stations which were exposed to different nitrogen concentrations. Stations on Huckleberry Creek generally had the lowest nitrogen concentrations and, following fertilization, were similar to the controls. Seventh Creek and its tributaries were higher; and Fourth Creek Stations 1 and 4 had the highest nitrogen concentrations (Figures 4, 5, 6, and 7).

In general, stations with high nitrogen concentrations, as well as those with low concentrations, were grouped together. Also, each cluster contains pre-fertilization dates. Groupings, however, appear to include similar size streams or flows during similar seasons. Cluster Ia is composed mainly of summer Huckleberry Creek samples. The samples from smaller streams contained in this group were generally collected in spring when flows were higher. Cluster Ib generally contained samples taken from the smaller streams during early spring. Cluster IIa consisted mainly of spring samples collected from Seventh Creek whereas IIb contained summer samples from both Seventh and Fourth Creeks. Cluster III lacked a high degree of intrafaunal homogeneity and primarily contains Fourth Creek samples collected during early spring. Samples from both large and small streams collected mainly during the summer and fall periods are contained in Cluster IV. Salal Creek again appeared to be unique and was the predominate station in Cluster V.

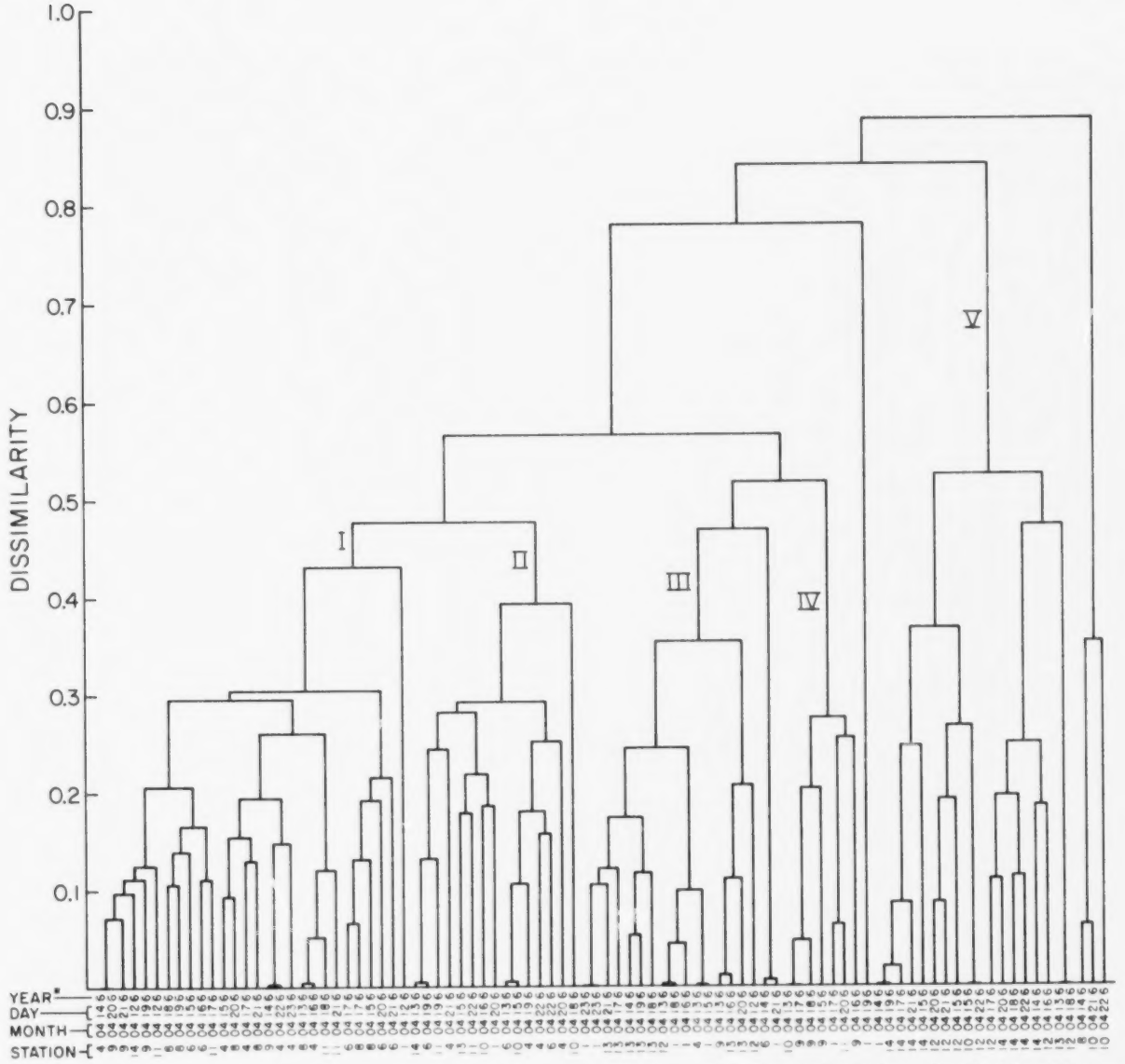

Figure 15. Dendrogram developd from cluster analysis of a Bray-Curtis dissimilarity matrix of drifting invertebrates before and during fertilization of Huckleberry Flats.

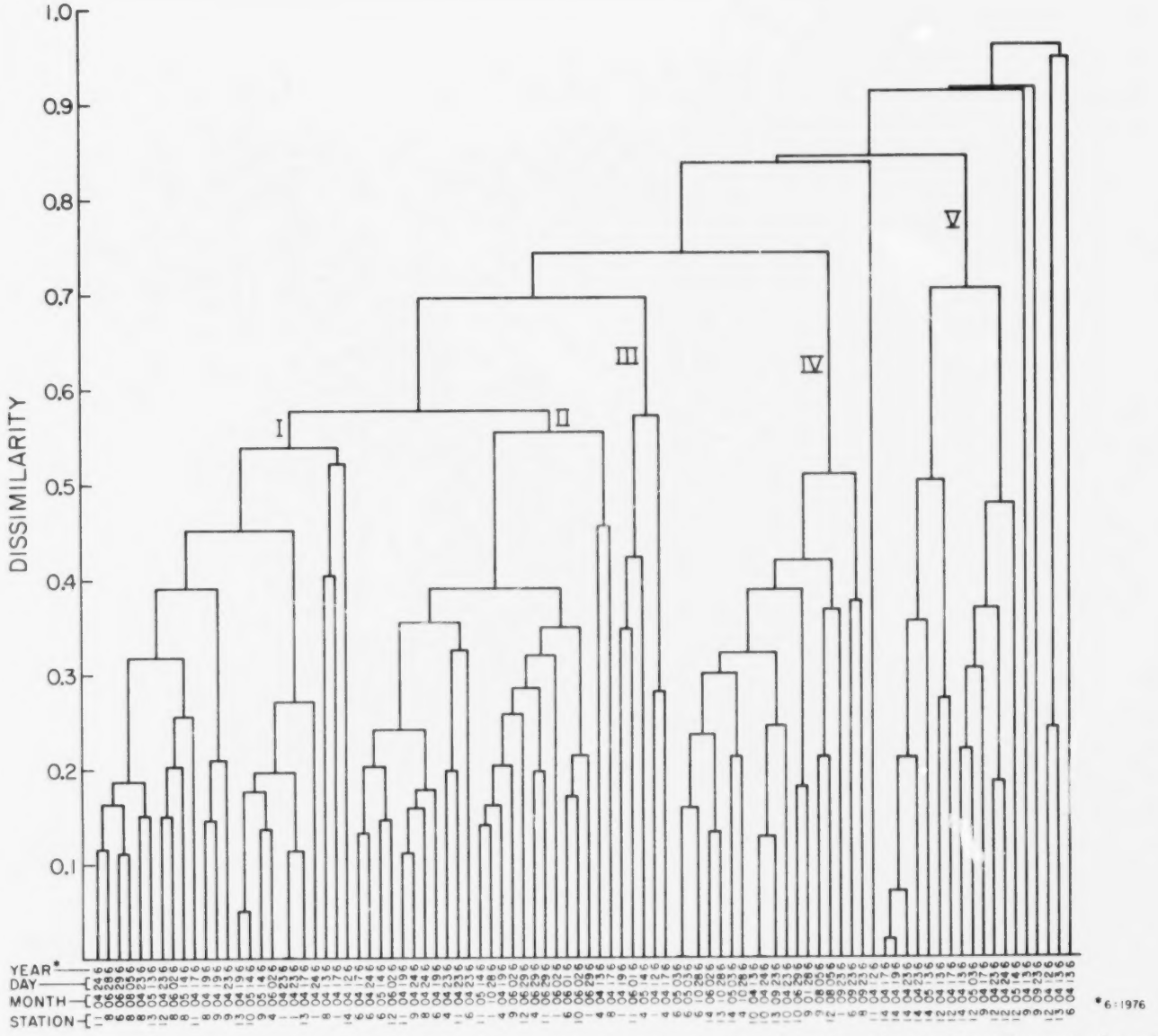

Figure 16. Dendrogram developd from cluster analysis of a Bray-Curtis dissimilarity matrix of drifting invertebrates before, during and after fertilization of Huckleberry Flats.

It appears that stream size, flow, and season were factors most common to each cluster. Although there were pre-fertilization samples contained in each major cluster, it is not possible to separate the long-term effects of the various degrees of contamination and stream size on the drift population. However, because each cluster of high faunal homogeneity contained samples from streams which were exposed to both low and high levels of nitrogen contamination, as well as samples collected prior to fertilization, it appears unlikely that fertilization had a major effect on invertebrate drift during the study period.

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